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MINERAL DETERMINATION BY MICROCHEMICAL METHODS

Lloyd W. Staples, *Stanford University, California.*

Historical Introduction

The value of the study of chemical reactions under the microscope and the recognition of precipitates by their characteristic geometrical and optical properties has long been known. As early as 1867 Wormley (28) published a treatise on the microchemistry of poisons. Bořický (4) was the pioneer in the application of microchemical tests to minerals. In 1877 he stated his hope of developing a "universal method" for analysis of rock-forming minerals by means of the recognition of the characteristic fluosilicates of the metallic elements. His work gave impetus to a rapid development of microchemistry, which movement lasted until the end of the century. During that period Streng, Haushofer, McMahon, Klement and Renard, Huysse, Behrens, and others made highly valuable contributions. How closely the development of microchemistry was associated with petrography and mineralogy is readily apparent on noting the principal field of interest of the above mentioned workers.

The work of Behrens (1) marked the greatest development of microchemistry up to the last decade. During the first quarter of this century there was a definite lag in interest and it was not without good reason that Lindgren (13) remarked in 1924, "And yet it seems to me that they (microchemical methods) have fallen into a sort of 'innocuous desuetude'; . . . several friends of the geological, yea even of the mineralogical brotherhood . . . have confessed that they never realized the possibilities of reactions on a glass slide, under the microscope, and have become quite enthusiastic."

Present Development in Mineralogy

During the last decade there has been a reawakening of interest in microchemistry. In the field of mineralogy this movement has come principally through the channel of the opaque minerals. McKinstry (14), and Putnam, Roberts, and Selchow (18) made helpful contributions and in 1931 Short (24) published a very complete and satisfactory description of microchemical tests in the limited field of the ore minerals.

Unlike the first rise in interest in microchemical methods, the present movement is welcomed more enthusiastically by chemists. Chamot and Mason's (5) textbook, written chiefly from the chemical viewpoint, is the most valuable general work on the subject in English. Due to the great interest of chemists, a periodical, *Mikrochemie*, has been established. The organization of a microchemical section by the American Chemical Society is further evidence of the growing importance of the subject.

As a result of this interest on the part of chemists it is not surprising that the development of microchemistry should move in a slightly different direction than it did under the influence of mineralogists and petrographers. The latter were well acquainted with the polarizing microscope and the study of crystallography, so they naturally used crystalline precipitates in their work. Under the influence of chemists a departure was taken from the use of crystalline precipitates, and color reactions have become more prominent. It is the writer's belief that since a mineralogist's training fits him so well for the study of crystals, and since a great deal of information may be obtained from them, crystalline precipitates should in general be preferred to color reactions in mineral testing.

In this renewed interest in microchemical methods, the nonopaque minerals have been greatly neglected. There are definite advantages to be gained from the application of microchemical methods to these minerals, and it is the purpose of this paper to pay special attention to tests that are useful in their determination.

ADVANTAGES AND DIFFICULTIES IN THE USE OF MICROCHEMICAL METHODS

The use of microchemical methods in mineral determination frequently results in a saving of material, reagents, and time. Microchemical testing may be used independently of other methods, but its greatest efficiency is most often found when it is used in conjunction with some other determinative method. Because of their dependence on the microscope, immersion methods and microchemical tests work very well when used to supplement each other. This is especially true in the case of minerals with overlapping indices of refraction, or with such good cleavage that complete index determination is made difficult. One can often obtain a quicker and more certain determination of a mineral by finding only one index of refraction and then making one or two simple microchemical tests than by attempting to get accurately all of the indices of refraction.

For the determination of minerals of high index of refraction, above about 1.74, it is difficult to obtain good stable index liquids and many laboratories are without these higher liquids. Consequently microchemical tests become of increasing importance for minerals of high index of refraction. Cerargyrite, for example, can be very simply determined by recrystallizing it in the form of octahedrons from an ammonium hydroxide solution, whereas its high index of refraction might prevent it from being determined by immersion methods in many laboratories.

The value of microchemical methods in the discovery and investigation of new minerals was noted by the writer in his work on the new mineral, austinite (25).

Aside from its value as a tool in determinative work, microchemical study provides excellent training in chemical and geometrical crystallography. The investigator learns to appreciate the phenomenon of isomorphism, and to one who is interested in the still little understood field of crystal growth, ample opportunity is provided for interesting experimentation. Crystals of the type shown in Fig. 6 permit the worker to attack the subject of geometrical crystallography from a viewpoint which is quite different from the conventional one.

Microchemical methods, like all other determinative methods, are not without their attendant difficulties. Failure to obtain satisfactory tests is usually due to one or more of the following causes: lack of technique on the part of the worker, failure to get the mineral in solution, inadequate or indefinite microchemical tests for certain elements, confusion due to interference by elements other than the one for which the test is being made, confusion due to isomorphous precipitates, or difficulty in recognition of crystals because of variation in habit. In spite of these difficulties, the advantages to be gained from microchemical methods are sufficient to recommend them strongly.

Although the application of microchemical methods to minerals has been investigated and developed over a long period of years, there remains ample opportunity for the improvement of tests and technique in this field. It is hoped that this article will prove a stimulus to work in this direction because it seems certain that intensive work will be well rewarded with the discovery of considerable valuable information.

Terminology: Microchemistry and Chemical Microscopy

"Microchemistry" is an old term and its original meaning was stated by the pioneer, Wormley (28), in his *Micro-Chemistry of Poisons*. He said: "By the term *micro-chemistry of poisons*, we understand the study of the chemical properties of poisons as revealed by the aid of the microscope . . . ." Because of the introduction of many new micro-methods in which the microscope was not used, Chamot and Mason (5) introduced "chemical microscopy" giving it practically the same meaning originally held by "microchemistry." "Microchemistry" is now taken to mean the chemical investigation of *small amounts* of material, regardless of the apparatus or technique used. "Chemical microscopy" requires the use of the *microscope*, but does not demand the use of small amounts of material or great sensitivity.

In making qualitative tests of the type discussed in this paper, the mineralogist will probably have one or more of the following purposes in mind: (1) to test for small amounts of replacing elements, such as for calcium and barium in strontianite, (2) to determine the mineral present when only a very small amount of material is available, (3) to determine the identity of a mineral with plenty of material available, but using small scale methods in order to save time or to be more certain of the results. According to Chamot and Mason's terminology, only the second of these would necessarily require "microchemical" tests, and if the microscope were used, all three would take advantage of "chemical microscopy." From this it will be evident that the mineralogist's main interest will be in "chemical microscopy" rather than "microchemistry" if the method of crystalline precipitates is used. However, as noted by Benedetti-Pichler (3), it is not always possible in practical work to separate completely these two branches of study.

At present the situation is one in which the term "chemical microscopy" is carefully used by chemists but generally disregarded by mineralogists. Mineralogists may feel that in this instance the degree of refinement required by chemists in their nomenclature is not necessary in the field of mineralogy. In any case, the adoption of a new term in any field will depend on whether that term fills a definite need.

It seems to the writer that the simple word "microchemistry" is to be preferred to the longer, less euphonious "chemical microscopy" when the meaning is clear. Since "microchemistry" is the more general term it includes the other and prevents the necessity of hair-splitting as to which term should be used. In those few cases where a comparison is to be made between various types of microchemical tests, such as between spot-tests[1] (Tüpfelreactionen developed by Feigl and Leitmeier) and chemical microscopic tests, the term "chemical microscopy" serves a real purpose and should be used.

REAGENTS

The number and kind of reagents required for microchemical testing of minerals will depend, of course, on the tests which are selected.

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[1] This type of reaction, applied to minerals, has recently been discussed by Watson (27).

Since no two workers will agree on which tests are best, and furthermore, since the fields of interest of investigators vary, it is impossible to give a list of reagents which satisfy all demands. There is also likely to be a difference in preference with regard to the use of liquids or solids. This is the case with potassium mercuric thiocyanate, ammonium paramolybdate, and disodium acid phosphate, which may be used either as solids or solutions. For the magnesium test in which magnesium ammonium phosphate is precipitated, all of the reagents may be put into a single solution which will then contain NH_4Cl, Na_2HPO_4, and NH_4OH. Most people prefer to add the reagents separately in this last case. Solid reagents usually keep better than solutions and react more slowly when placed in a test drop. Solutions produce quicker reactions, they permit better control of concentrations, and there remain no undissolved remnants of the reagent to obscure or confuse the test.

For general mineralogical work, more reagents will be required than those listed by Short (24), since he is only concerned with the restricted field of the ore minerals. However it is not necessary to have the great number of reagents suggested by Chamot and Mason (5). The writer uses about 25 reagents in most of his work and keeps these in three groups.

(1) The solvents are kept in small ground-stoppered bottles in a wooden block (22×7×3 cm.), called the solvent block. The most frequently used solvents are HCl (2:3), H_2SO_4(1:4), HNO_3 (1:1), and NH_4OH (conc.). Each reagent bottle has its individual dropping pipette. The pipettes are made out of glass tubing and are superior to glass rods because the quantity of liquid to be delivered can be better regulated.

(2) A wooden block 19 cm. long and 11 cm. wide is constructed to hold the reagent vials. The block is arranged with steps, each step standing about 1 cm. above the one in front of it, and holding 6 vials. Vials which are 45×15 mm. are of a convenient size for this work. The solutions are kept in the vials in the first row and when a drop is needed it is transferred by a platinum wire with a loop in the end of it. The following reagents are kept in the reagent block: ammonium paramolybdate (ordinary "ammonium molybdate"), disodium acid phosphate, chloroplatinic acid, potassium mercuric thiocyanate, potassium iodide, silver nitrate, calcium acetate, sodium dicarbonate, sodium chloride, uranyl acetate, ammonium chloride, ammonium dichromate, cobalt nitrate, cesium chloride, potassium sulfate, dimethylglyoxime, fluorite, sodium bismuthate, iron filings, potassium thiocyanate, and potassium ferrocyanide. The uranyl acetate is wrapped in paper so that it will not come in contact with the glass of the vial.

(3) The less frequently used reagents and solvents should be kept near at hand but not on the desk of the worker, since an overcrowded desk decreases efficiency. In this group are the concentrated acids and some of their commonly used dilutions.

APPARATUS

An advantage of the use of microchemical methods in mineralogy is that very little apparatus ordinarily is required. The apparatus is described in those texts dealing with microchemical methods, and only a few additional remarks will be made here.

A good polarizing microscope should be used for this work. With proper precautions the use of chemicals will not injure the instrument, and consequently it is not necessary to handicap one's self with a poor instrument because of fear of injuring a good one.

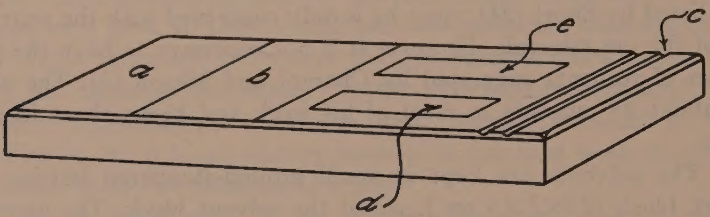

FIG. 1. TESTING BLOCK

(a) Area painted black, (b) area painted white, (c) grooves for holding glass tubes and platinum wire, (d) asbestos pad, (e) mirror.

An alcohol lamp provides the best source of heat for microchemical work. The lamp can easily be made from a drawing-ink bottle, a cork, a piece of string to serve as a wick, and a section about 3 cm. long of an old blowpipe to act as a guide for the wick through the cork. A Bunsen burner should be available for making fusions.

Glass slides of the size used in petrographic work (25×45 mm.) are preferable to the larger slides used in biological work because the latter often extend over the edge of the microscope stage and are likely to be knocked off. The cleaning of slides is important but it is not necessary to be as careful with it as has frequently been recommended. A good scrubbing with soap and water, and rinsing in distilled water is usually sufficient. If they are dried with a paper or cloth towel, any lint deposited may be removed with a silk cloth. The other alternative is to let the water evaporate from them, but this obviously requires a longer time. All of the glassware should be cleaned periodically with sulfuric-chromate cleaning solution.

The writer has found considerable use for what he calls a "testing block." The accompanying illustration shows the general arrangement of the wooden block, which is 20×11cm. in plan and 2 cm. high. It consists of an area (a) painted black, an area (b) painted white, an unpainted portion containing two grooves (c), a rectangular piece of asbestos pad (d), and a mirror (e). The main purpose of the block is to provide a place on which to set slides while adding reagents and from which slides can easily be picked up. Hot slides may be placed on the asbestos pad. The colored areas provide contrasting backgrounds for small amounts of material. If a slide with a drop on it is placed on the mirror the boundaries of the drop and its color are often made more definite. The grooves are used for holding the platinum wire and other pieces of apparatus. By permitting glass tubes to extend out over the edge of the block they are kept from being contaminated by contact with the desk.

A piece of 4 mm. glass tubing with a fine platinum wire extending out of it for about 5 mm. is useful for joining drops on the glass slide. A pointed glass rod may be used for the same purpose but it has the disadvantage that the fine tip breaks off too easily.

SELECT MICROCHEMICAL TESTS

Table 1 presents a summary of those microchemical tests which have been found to yield the most satisfactory results in mineral determinative work. The material in the table is intended to recall some of the important details of these tests, but is not sufficient to act as a guide for the performance of the tests for persons who are not already acquainted with them. For a more complete description of the tests reference should be made to the section on microchemistry by the writer in Rogers' textbook (20), or to the work of the author whose initial follows the reagent, thus (C) refers to Chamot and Mason (5), (S) to Short (24), (B) to Behrens and Kley (2). An asterisk in place of an initial indicates that a description of the test, or new material pertaining to it, is to be found in this paper following the table.

The hydrogen ion concentration of the test drop which will give the best conditions for precipitation of characteristic crystals is not noted in the table. In every case the acid should be dilute. Short recommends the use of 1:7 HNO_3 and 1:5 HCl for all those tests which are marked with his initial (S). All other tests may be performed in 1:1 HNO_3, 2:3 HCl, or 1:4 H_2SO_4. In the case of exception to these rules, the degree of acidity is noted in the table.

Only the most characteristic habits of the precipitates are listed. When no color is given for the precipitate it may be assumed that it is colorless or nearly so.

TABLE 1

Elements	Reagents	Test Drop	Description of Precipitate
Aluminum	NH_4 molyb.*	Neutral	NH_4 alum. molyb. Tab. xls. with sym. extinction.
	CsCl (B)	H_2SO_4	Cesium alum. Octahedra.
Antimony	KI & CsCl (S)	HCl	$SbI_3 \cdot 3CsI$. Orange hexs. or stars.
Arsenic	NH_4 molyb. (S)	HNO_3	NH_4 arsenomolyb. Small yellow octahedra.
	KI *	HCl	AsI_3. Orange hex. plates, stars, powder.
Barium	$K_4Fe(CN)_6$ (C)	NH_4Cl, HAc	$K_2BaFe(CN)_6 \cdot 5H_2O$. Rhombs, sym. extinction.
	HCl *	HCl	$BaCl_2 \cdot 2H_2O$. Mono. xls., polysynthetic twins.
Bismuth	KI & CsCl (S)	HCl	$BiI_3 \cdot 3CsI$. Rose-red hexs., stars.
Borates	HCl *	HCl	H_3BO_3. Pseudo-hex. plates & branching forms.
Calcium	H_2SO_4 (C)	HCl	$CaSO_4 \cdot 2H_2O$. Mono. xls., length-fast, low biref.
	*		$CaSO_4 \cdot \frac{1}{2}H_2O$. Orth. xls., length-slow, higher biref.
Chlorides	$AgNO_3$ (C)	HNO_3	AgCl. Adam. octahedra. (Recrystallize from NH_4OH)
Chromium	$AgNO_3$ (C)	HNO_3 (1%)	Ag_2CrO_4, $Ag_2Cr_2O_7$. Ruby-red pleochroic xls.
Cobalt	$K_2Hg(CNS)_4$ (S)	HNO_3	$CoHg(CNS)_4$. Blue prisms, spherulites.
Copper	$K_2Hg(CNS)_4$ (S)	HNO_3	$CuHg(CNS)_4$. Yellow branching aggregates.
	Iron filings *	Neutral	Copper trees on filings.
Fluorides	NaCl & soluble silicate (B)	HNO_3	Na_2SiF_6. 6-sided xls., low index.
Iron	$K_2Hg(CNS)_4$ (S)	HNO_3	Red coloration.
	NH_4Cl *	HNO_3	Mixed xls., double salt. Brown, isom, orth.

TABLE 1. (*Continued*)

Elements	Reagents	Test Drop	Description of Precipitate
Lead	KI (S)	HAc (0.5%)	PbI_2. Yellow hex. plates.
	HCl (C)	HNO_3	$PbCl_2$. Adam. prisms, aggregates.
Magnesium	Na_2HPO_4 (C)	NH_4OH	$MgNH_4PO_4 \cdot 6H_2O$. Feathery X's, "house tops."
Manganese	NH_4 molyb. *	Neutral	NH_4Mn. molyb. Pleochroic orange laths.
	$NaBiO_3$ (S)	HNO_3	Purple-pink coloration.
Mercury	$Co(NO_3)_2 \cdot 6H_2O$, & KCNS (S)	HNO_3	$CoHg(CNS)_4$. Blue prisms, spherulites.
Molybdenum	Na_2HPO_4 & NH_4Cl (B)	HNO_3	NH_4 phosphomolyb. Small yellow octahedra.
	HCl *	HNO_3	Blue fine-grained ppt. on evap.
Nickel	Dimethylglyoxime (C)	NH_4OH	$Ni(C_4H_7N_2O_2)_2$. Pink acicular xls.
Phosphates	NH_4 molyb. (C)	HNO_3	NH_4 phosphomolyb. Small yellow octahedra.
	$AgNO_3$ (C)	Neutral	Ag_3PO_4. Yellow 3-armed xls.
Potassium	H_2PtCl_6 (C)	HCl	K_2PtCl_6. Yellow octahedra.
	HCl *	HCl	KCl. Isom. xls.
Silicon	CaF_2, H_2SO_4, NaCl *	HNO_3 (1:7)	Na_2SiF_6. 6-sided plates, stars. Low index.
Silver	HCl (S)	HNO_3 (1:1)	AgCl. Adam. octahedra. (Recrystallize from NH_4OH)
	$(NH_4)_2Cr_2O_7$ (S)	HNO_3 (1%)	Ag_2CrO_4, $Ag_2Cr_2O_7$. Ruby-red or yellow xls.
Sodium	Uranyl Ac. (B)	Neutral	Na uranyl Ac. Tetrahedra.
	HCl *	HCl	NaCl. Isom. xls.
Strontium	$(NH_4)_2Cr_2O_7$ (C)	NH_4OH	$SrCrO_4$. Yellow globules, sheaf-shaped groups. Soluble in HAc.
	H_2SO_4 (C)	HNO_3	$SrSO_4$. Rhombs, dagger-shaped xls.

TABLE 1. (*Continued*)

Elements	Reagents	Test Drop	Description of Precipitate
Sulfates	CaAc (C) *	HCl	$CaSO_4 \cdot 2H_2O$. Mono. xls., ext. angle $= 37\frac{1}{2}°$ $CaSO_4 \cdot \frac{1}{2}H_2O$. Orth. xls., parallel ext.
Tin	NH_4Cl *	HCl	$(NH_4)_2SnCl_6$. Large octahedra
	CsCl (S)	HCl	Cs_2SnCl_6. Minute octahedra. Sensitive test.
Titanium	H_2O_2 (C)	HCl	Yellow, orange coloration.
Tungsten	Na_2HPO_4 & NH_4Cl (B)	HNO_3	NH_4 phosphotungstate. Small octahedra.
	HCl *	HNO_3	Yellow granular ppt.
Uranium	NaAc (B)	Neutral	Na uranyl Ac. Tetrahedra.
Vanadium	HNO_3 *	HNO_3	V_2O_5. Dense red ppt. on evap.
Zinc	$K_2Hg(CNS)_4$ (S)	HNO_3	$ZnHg(CNS)_4$. Branching aggregates.
	$NaHCO_3$ (C)	Neutral	Double carbonate. Tetrahedra.

DISCUSSION OF CERTAIN TESTS

The tests discussed in the following pages are either new tests, those inadequately described in the literature, or tests concerning which new material has been developed. Only those tests marked with an asterisk in table 1 are described here. They are discussed in alphabetical order, according to the elements for which they are to be used.

Most of the tests discussed here have a limit of sensitivity of about 0.1% of the normal salt of the element. This is a lower sensitivity than that attained in many of the standard reactions, but for mineralogical work it is frequently preferable to use tests that are not too delicate. Also, it is well to have on record several tests of different sensitivities for each element, in order to gain a more accurate idea of concentrations.

A few of the precipitates described are formed on evaporation of the acid solution of minerals. These precipitates are often unexpectedly met when working on unknowns and should be recognized. In this class are sodium chloride, potassium chloride, barium chloride, boric acid, vanadium pentoxide, and the oxides of molybdenum and tungsten. Microchemical gypsum or calcium sulfate hemihydrate may also be formed under these conditions from minerals which contain both calcium and sulfate.

ALUMINUM

Ammonium Paramolybdate.[2] (New test.) If a drop of the acid solution of an aluminum mineral or its fusion is evaporated to dryness and a drop of a saturated water solution of ammonium paramolybdate added, crystals of ammonium aluminum dodecamolybdate will form. According to Hall (9) the formula for this compound is $3(NH_4)_2O \cdot Al_2O_3 \cdot 12MoO_3 \cdot 19H_2O$, but there is some uncertainty as to whether it contains 19 or 20 molecules of water.[3] The crystals (Figs. 1 and 2) are readily recognizable because they occur as rhomb-shaped tabular plates with an angle of 86°. They have symmetrical extinction and their fast ray direction is parallel to the long diagonal. The indices of refraction for the fast and slow ray directions of the plates are $n_s = 1.741$ and $n_f = 1.700$, both ± 0.003, and the birefringence is 0.041 ± 0.006. It is difficult to obtain complete data on the crystals because of their thin tabular habit. By measurement of several plates which were standing on end, the average thickness was found to be about 8μ. This value for the thickness is corroborated by a calculation from the birefringence. The interference color of the single plates is usually white or yellow of the first order and this would indicate a thickness of less than 10μ. The plates when turned on edge seem to have parallel extinction so the crystals probably belong to the orthorhombic system.

As the plates grow they tend to pile up on each other with a slight rotation. Another characteristic is the saddle-shape curvature of many of the plates.

Ferric iron produces a precipitate which is isomorphous with the aluminum compound. Ammonium ferric dodecamolybdate may be distinguished from ammonium aluminum dodecamolybdate by adding an excess of NH_4OH to the drop. Both of the above compounds are soluble in this reagent but the iron compound becomes yellow-brown on dissolving while the aluminum salt remains colorless.

This new test for aluminum has a limiting sensitivity of about 0.1% aluminum chloride and consequently it is not so sensitive as the cesium alum test. It has an advantage over the latter in that a less expensive reagent is used. The difficulty in the isomorphism of the iron and aluminum compounds is shared by both tests, although this has not always been recognized in the case of the cesium test.

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[2] Since my work with this reagent, I have come across a note in *Chemical Abstracts* of an article by C. van Zijp (*Pharm. Weekblad.*, Band **72**, pp. 414–418, 1935) in which he discussed the use of ammonium molybdate as a microchemical reagent.

[3] Rosenheim and Schwer (23) give the formula $(NH_4)_3H_6[Al(MoO_4)_6] \cdot 7H_2O$ which is equivalent to $3(NH_4)_2O \cdot Al_2O_3 \cdot 12MoO_3 \cdot 20H_2O$.

ARSENIC

Potassium Iodide. The precipitation of arsenic as AsI_3 is a valuable microchemical test because it can be used to distinguish between arsenic and antimony, and between arsenates and phosphates. The latter distinction is especially important in the nonopaque minerals. The best test for arsenates and phosphates is the precipitation of the arsenomolybdate or phosphomolybdate by means of ammonium paramolybdate, but this does not provide a safe distinction between the two, although it usually suggests which is present.

The descriptions of the potassium iodide test for arsenic to be found in the literature are either incomplete or faulty. The lack of uniformity in results obtained by various writers depends chiefly on the concentrations of arsenic salts present and on the strength of the acid used.

The best conditions for obtaining a characteristic precipitate of AsI_3 are produced when about a 1% solution of an arsenic salt is being tested. The salt should be dissolved in 2:3 HCl and a grain of KI added. A stronger concentration of the acid may be used, but very dilute acid should be avoided. The precipitate obtained with the concentrations described above consists of a fine yellow-orange powder from which hexagonal plates roll out (Fig. 3). The plates have the following properties: uniaxial negative, adamantine luster, predominantly yellow by transmitted light and orange by reflected light. Prisms, 3-sided plates, and 6-rayed stars also may form. Occasionally surface films give the plates a greenish color.

With very dilute acids and with low concentrations of arsenic (below about 0.5% K_3AsO_4) the characteristic crystals do not form, but instead a fine granular precipitate is developed. With very dilute acids and high concentrations of arsenic, orange spherulites may develop.

Strong HNO_3 should not be used in place of HCl because the former breaks down the reagent. Black opaque crystals of iodine are frequently encountered in strong acid solutions when using KI as a reagent, but these are easily recognized.

It is evident from the description given above of the plates of AsI_3 that they closely resemble the hexagonal plates of PbI_2 which are used as a test for lead (compare Figs. 3 and 4). Unless the conditions of precipitation are studied, confusion of lead and arsenic may result. The precipitation of PbI_2 should be made only in very dilute HNO_3 or acetic acid solutions and under these conditions typical crystals of AsI_3 are not easily formed. On the other hand, AsI_3 should be precipitated in strong HCl solutions and under these conditions good crystals of PbI_2 will not develop. The formation of $PbCl_2$ will indicate the presence of lead. Although an experienced worker may prove the presence of both lead and arsenic, as in mimetite, by using KI and noting the difference in the color of the crystals of the precipitate and the different conditions under which precipitation is obtained, it is usually well to use other tests for these elements when they occur together.

A yellow coloration is obtained on adding KI to solutions of antimony, bismuth, and tin salts. Copper gives a crystalline precipitate with KI but the crystals are not likely to be confused with the typical plates of AsI_3.

BARIUM

Hydrochloric Acid. Crystals of barium chloride ($BaCl_2 \cdot 2H_2O$) may be obtained on evaporating HCl solutions of barium salts. The crystals, which are monoclinic, usually show polysynthetic twinning in more than one direction and consequently are easily recognized. The chlorides of strontium or calcium do not give isomorphous precipitates.

The use of barium chloride as a microchemical test for barium was first discussed by McMahon (15) in 1893. The test has been used for many years by Professor A. F. Rogers (19) who discovered it independently and has found it very useful.

BORATES

Hydrochloric acid. Acid solutions of borates produce crystals of boric acid when evaporated. The crystals (Fig. 5) belong to the triclinic system and have two different aspects depending on the orientation. Both are characteristic and usually occur together. The crystals appear either as pseudo-hexagonal plates with low birefringence, or branching tree-like forms with striations transverse to their length and higher birefringence. The branching aspect represents a side view of an aggregate of plates.

CALCIUM AND SULFATE

Sulfuric acid or calcium acetate. The precipitation of microchemical gypsum ($CaSO_4 \cdot 2H_2O$) is one of our most satisfactory microchemical tests. In spite of the frequency with which it is used and the great detail with which it is described in textbooks, there has been no mention of a modification of it which frequently occurs. In the presence of a high concentration of sodium ions, orthorhombic pseudo-hexagonal prisms form either along with microchemical gypsum or alone. The crystals (Fig. 12) have parallel extinction and when they are lying on a prism face show higher birefringence than microchemical gypsum. They are length-slow, while microchemical gypsum is length-fast. The hexagonal cross-sections of the prisms show twinning under crossed nicols. These crystals are probably the hemihydrate ($CaSO_4 \cdot \frac{1}{2}H_2O$) which has recently

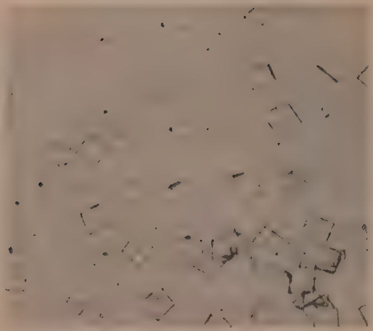

FIG. 1. Ammonium aluminum molybdate. Single crystals. ×220.

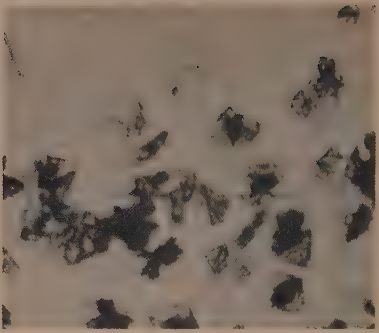

FIG. 2. Ammonium aluminum molybdate showing the manner in which crystals group themselves. ×110.

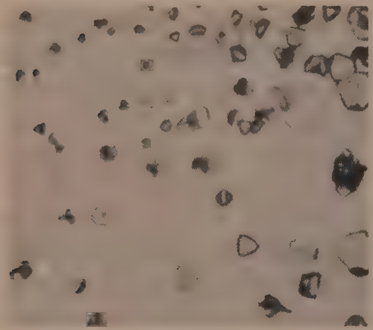

FIG. 3. Arsenic iodide. The orange hexagonal plates are the most characteristic. ×110.

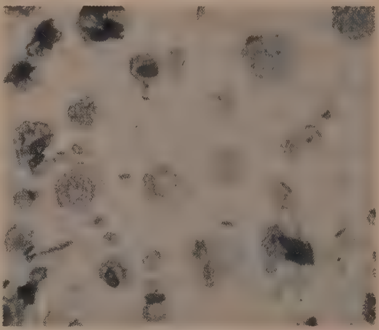

FIG. 4. Lead iodide. Note similarity to crystals in Fig. 3, formed by same reagent. ×220.

FIG. 5. Boric acid. The plates show low birefringence while the branching forms have higher birefringence. ×40.

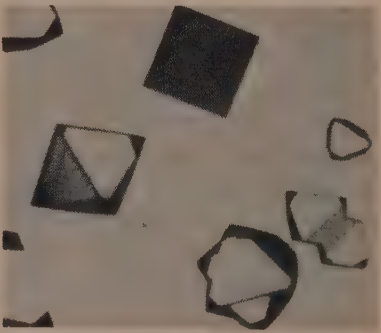

FIG. 6. Ammonium chlorostannate. The single crystals lie almost perpendicular to 2-, 3-, and 4-fold axes of symmetry. A spinel twin and a parallel growth are also present. ×110.

been discussed by Gaubert (7). The hemihydrate may be produced even in the absence of sodium from the HCl solutions of some minerals on the addition of dilute H_2SO_4. It is also formed directly in the dilute HCl solution of minerals, such as wilkeite, which contain both calcium and sulfate. The hemihydrate produced under these conditions may look very much like typical microchemical gypsum until it is tested optically.

Grengg (8) has noted the transformation of gypsum to the hemihydrate in concentrated solutions of NaCl or $MgCl_2$, but the presence of chlorine ions is not necessary for the direct precipitation of the hemihydrate. Magnesium ions do not seem to be so important in inducing the precipitation of the hemihydrate as are sodium ions, and generally the influence of magnesium is not noticeable.

COPPER

Iron filings. The formation of copper "trees" provides a spectacular and convincing test for copper. One or two very small filings (less than 1 mm. in length) taken from an ordinary nail, are placed in the test drop. The drop should be neutral or only very slightly acid, since concentrated acids attack the iron too rapidly. If copper is present it will coat the iron filings and sprout out from them in dendrites and trees. The color of the copper is best observed by shutting out the transmitted light either with the hand or by tilting the mirror.

The potassium mercuric thiocyanate test for copper is very satisfactory but under certain conditions, such as when considerable iron is present, the copper-trees test has been found useful. The limiting concentration under which this test works is about 0.05% copper sulfate. The precipitation of copper may be hindered or even completely prevented if considerable lead is present.

The precipitation of metallic trees may be used for many elements as has been shown by Chamot and Mason (5), but the test described here is the only one of this type used by the writer. Dr. A. F. Rogers worked out this test independently and has used it successfully for many years.

IRON

Ammonium chloride. (New test.) The following test for iron was discovered in an attempt to find one that would be somewhat less sensitive than the thiocyanate test and would yield a crystalline precipitate instead of giving a color reaction. The test satisfies both of these requirements and in addition is somewhat quantitative. It works under either acid or neutral conditions and the only reagent needed is NH_4Cl.

The iron mineral should be dissolved in HNO_3 in order to oxidize all iron to the ferric state. On addition of a drop of HCl to the solution there is produced a coloration which is yellow to brown, depending on the concentration of ferric ions. A large grain of NH_4Cl is placed in the test drop and allowed to dissolve. The drop is then heated until evaporation produces a precipitate at the border of the drop. Depending on the concentration of the ferric ions in the drop and also on the speed and extent to which evaporation has taken place, various characteristic results will be obtained. With high concentrations of iron, brown orthorhombic highly birefringent crystals (Fig. 7), usually composed of two rhombic prisms and often pseudo-octahedral, will form. This is the double salt $FeCl_3 \cdot 2NH_4Cl \cdot H_2O$ which was discovered almost a century ago by Fritzsche (6).

The second type of crystals, which will be called "anomalous mixed crystals of ammonium chloride and ferric chloride", are more characteristic of solutions containing low concentrations of iron. They frequently occur as individual malformed yellow or orange cubes and octahedrons.[4] The octahedrons usually show a blue or green anomalous interference color under X-nicols, and in some cases they develop directly from cubes. The cubes often have rounded edges and are most characteristic when they show a pleochroism in quadrants (Fig. 8). When octahedrons develop from cubes, the lines separating the pleochroic quadrants become octahedron edges. If only a very little iron is present in the solution, instead of individual crystals developing there will be a thickening and yellow coloration of the tips of the usual NH_4Cl lattice-like precipitate. Also characteristic of this test is the segregation of the yellow coloration of the solution to the vicinity of growing crystals, leaving the rest of the solution colorless.

Concentrations as low as 0.1% ferric chloride can be tested in this way. With concentrations above about 1%, crystals of both the double salt and anomalous mixed crystals frequently are obtained in the same drop.

The anomalous mixed crystals of ammonium chloride and ferric chloride have been known for a long time and although a great deal of work has been done on them, especially by chemists, there still remains considerable uncertainty regarding them. Lehmann (12) was the pioneer in the study of these crystals and he expressed the opinion that they represent a crystallization of the double salt with NH_4Cl. He also published a good colored plate showing the gradation in the forms of the crystals. Roozeboom (21) did not agree with Lehmann that the coloration was due to a crystallization of the double salt with NH_4Cl, but thought that it was due to a crystallization with a hydrated ferric chloride. He did not know the type of mixture. Mohr (16) agreed with

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[4] For the sake of convenience the isometric form names are used, although it is realized that the optical properties are not in accordance with these names.

Lehmann that the double salt was mixed with NH_4Cl and he also stated that the crystals do not represent a mechanical mixture of the two compounds, but that they are a homogeneous chemical mixture. Johnsen (10) decided against the color being due to the double salt and called these anomalous mixed crystals. He says that according to phase law the crystals are homogeneous mixtures and possibly form a transition between an isomorphous mixture and a microscopic intergrowth. Neuhaus (17) recently worked on these crystals and came to the conclusion that they are not double salts or mixed crystals, but rather represent the inclusion of foreign matter along certain faces of the NH_4Cl crystals. He also recommended calling them anomalous mixed crystals.

Similar anomalous mixed crystals are formed by NH_4Cl with cobalt, nickel, manganese, copper, and cadmium. None of these causes confusion with the iron test and the writer would not recommend any but the mixture with the iron salt to be used as a microchemical test.

MANGANESE

Ammonium Paramolybdate. (New test.) The following test for manganese is valuable in that it gives a readily recognized crystalline pleochroic precipitate, it can show the presence of both manganese and iron simultaneously, and the reagent is common and inexpensive.

A drop of the solution of the mineral or its fusion should be evaporated to dryness to remove all free acid. A little solid ammonium paramolybdate is placed in the center of the dried-up area and a drop of water added. If manganese is present, characteristic crystals will form at the edge of the drop in a few minutes. Very good tests may be obtained from solutions of 1% manganese chloride and the limit of the reaction is about 0.1% of the salt.

The crystals produced in this test (Fig. 9) are colorless in the direction of the fast ray, and yellow to reddish-orange, depending on the thickness, in the direction of the slow ray. They are length-slow and have parallel extinction. Parallel growths, producing reentrant angles and swallow-tail terminations are common, but twinning has not been observed. Frequently, in addition to the crystals a yellow granular precipitate is formed. No other element gives similar precipitates and since ammonium ferric dodecamolybdate is not isomorphous and forms under the same conditions as the manganese salt, it can be precipitated simultaneously (Fig. 10).

The formula of the ammonium manganese molybdate which is precipitated in this test is $(NH_4)_3H_7[Mn(MoO_4)_6]\cdot 3H_2O$ according to Rosenheim (22) who prepared and analyzed crystals which are probably the same as those produced in this test.

MOLYBDENUM AND TUNGSTEN

Hydrochloric Acid. The precipitation of the yellow phosphomolybdate or white phosphotungstate is useful as a group reaction but it cannot always be used to distinguish between molybdenum and tungsten compounds because the color difference may not be marked. One reason for the difficulty frequently encountered in obtaining precipitates of the phosphosalts, especially the phosphotungstate, is that insoluble oxides are formed on treating the mineral with acid. These oxides are soluble in NH_4OH and therefore the test may be made by dissolving the acid residue in this base, adding Na_2HPO_4 and then acidifying with HNO_3.

The following procedure is a quick one for distinguishing between molybdenum and tungsten minerals. The mineral is dissolved in HNO_3 and the drop evaporated to dryness. A drop of HCl is added and this is likewise evaporated. If the mineral is a tungsten compound the yellow oxide, WO_3, will quickly be formed. If molybdenum is present, a dark greenish-blue oxide will appear after stong heating. In the case of molybdates soluble directly in HCl, the molybdenum-blue coloration of the powder can be quickly brought out by the addition of a drop of H_2O_2 to the residue obtained by evaporating the HCl solution to dryness.

POTASSIUM (see SODIUM)

SILICON

Fluorite, Sodium Chloride, and Sulfuric Acid. A description of the details of this test has recently been published by the writer (26). The materials needed for the silicon test are a small platinum spoon, a block of charcoal, a small tripod, and a celluloid slide. The reagents required are sulfuric acid, nitric acid, sodium chloride, and pure fluorite. The test employs the well-known precipitate of sodium fluosilicate which was originally described by Bořický as a test for sodium. This precipitate is interesting in that it has the lowest index of refraction of any crystalline substance with the exception of ice.

The test gives good results on all silicon-bearing minerals in 10 minutes or less, and the only element known to give an isomorphous precipitate under the conditions of the test is germanium. Because of the rarity of germanium minerals, this isomorphism causes no difficulty.

SODIUM AND POTASSIUM

Hydrochloric Acid. Evaporation of HCl solutions of sodium and potassium salts produces isometric crystals of NaCl and KCl. The most common habits are the cube and skeletal growths. These are so frequently encountered in the testing of unknowns that it is well to recognize them.

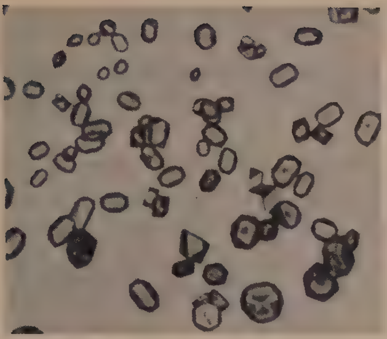

FIG. 7. Orthorhombic crystals of the double salt of ammonium chloride and ferric chloride. ×110.

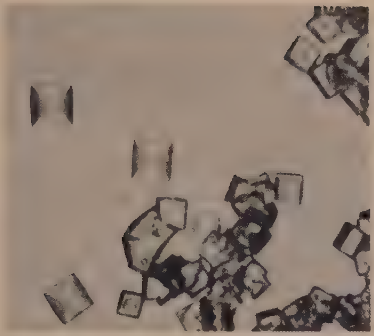

FIG. 8. Anomalous mixed crystals of ammonium chloride and ferric chloride showing cubes with pleochroism in quadrants, and octahedrons. ×110.

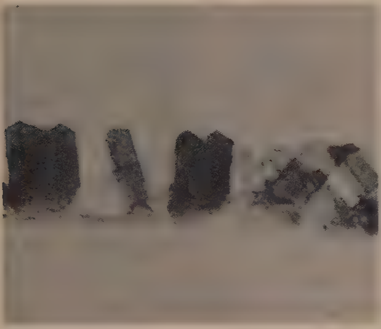

FIG. 9. Ammonium manganese molybdate developed at edge of drop. Strong pleochroism is apparent. ×110.

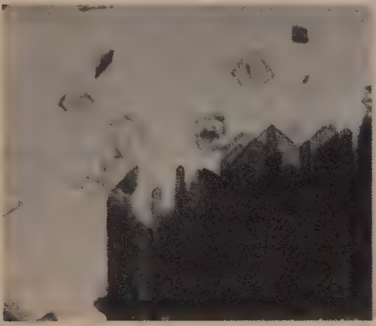

FIG. 10. Simultaneous precipitation of plates of ammonium ferric molybdate and red prisms of ammonium manganese molybdate. ×110.

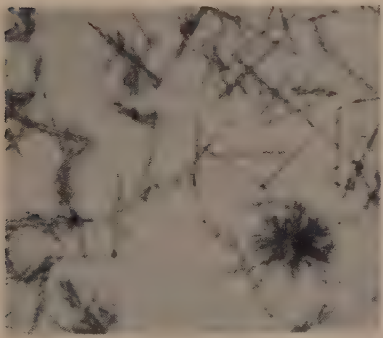

FIG. 11. Typical crystals of microchemical gypsum ($CaSO_4 \cdot 2H_2O$). ×110.

FIG. 12. Crystals of calcium sulfate hemihydrate ($CaSO_4 \cdot \frac{1}{2}H_2O$). Compare with the more common crystals of microchemical gypsum in Fig. 11. ×220.

The precipitation of NaCl is fairly sensitive, giving definite results in solutions containing 0.05% of the salt. Dilute HCl is used as the precipitant.

It is interesting to note that from solutions containing about equal amounts of sodium and potassium, the chlorides of these elements will be precipitated separately, not as isomorphous mixtures. The chlorides can be distinguished from each other by removing the liquid by evaporation, dislodging the crystals, and adding a drop of clove oil. The crystals of NaCl have a slightly higher index of refraction than clove oil while those of KCl have a lower index than the oil.

SULFATES (see CALCIUM)

TIN

Ammonium Chloride. The precipitation of tin using CsCl or RbCl is a very good test but with either reagent the octahedrons of the chlorostannate which form are very small. Large crystals (Fig. 6) may be obtained by the use of the more common and less expensive reagent, NH_4Cl, following the same procedure as though CsCl were used. This test gives excellent results with solutions containing about 0.5% or more stannic chloride. For lower concentrations one must resort to the less satisfactory precipitate of cesium or rubidium chlorostannate.

Cassiterite, the most common tin mineral, can easily be tested by following a method similar to the one used in ordinary mineral determinative work. A small grain or some of the powder of the mineral, preferably the former, is placed on a small piece of zinc and this is put in HCl for a few minutes. After the zinc has dissolved, the solution is evaporated to dryness, a drop of HNO_3 added and evaporated for the purpose of oxidizing and dissolving the tin, and the test drop is then again acidified with HCl. On addition of a grain of NH_4Cl, large octahedrons of $(NH_4)_2SnCl_6$ are formed. The second most common tin mineral, stannite, may be dissolved directly in HNO_3 and the evaporated drop tested with HCl and NH_4Cl.

TUNGSTEN (see MOLYBDENUM)

VANADIUM

Nitric Acid. The presence of vanadium can readily be shown by dissolving the mineral in HNO_3 and evaporating the solution to dryness. A dense red precipitate of vanadium pentoxide (V_2O_5) is formed. This test is not so satisfactory as a good crystalline precipitate would be, but in the absence of other easily performed and definite tests it frequently serves a valuable purpose. The precipitation of V_2O_5 was used many years ago by Lacroix (11).

ACKNOWLEDGMENTS

The writer wishes to acknowledge his indebtedness to Professor A. F. Rogers for the many valuable suggestions he has offered during the course of this work and for a helpful criticism of the manuscript.

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MAGNETITE METACRYSTS

G. M. SCHWARTZ, *University of Minnesota, Minneapolis, Minnesota.*

INTRODUCTION

The occurrence of abundant and even conspicuous metacrysts of magnetite in the iron formation of the Nemo region of the Black Hills attracted the writer's attention to magnetite as a metacryst in metamorphic rocks. Magnetite is well known to have a strong crystallizing power and it corresponds well with Becke's[1] statement that minerals in schists with compact molecular arrangement are most likely to take on crystal form, but Becke did not list magnetite in his series of form development. Grubenmann omitted magnetite in 1904, but Grubenmann and Niggli[2] in 1924 give it last in a list of porphyroblastic minerals. Magnetite is not given by Leith and Mead[3] among the common idiomorphic minerals in schists but their list is indicated as not complete. Grout[4] lists magnetite among the minerals common as metacrysts.

The writer studied available material and presents the following descriptions as typical of the occurrence of magnetite metacrysts and their relations to other minerals in porphyroblastic rocks. Magnetite does not form metacrysts as commonly as garnet but it is more common than some of the minerals usually emphasized.

DESCRIPTION OF MAGNETITE METACRYSTS

In the iron ores of the Lake Superior district magnetite crystals are not infrequently larger than most other minerals in the ores and protores. Gruner[5] shows an euhedral crystal of magnetite replacing hematite and gangue, and a somewhat similar occurrence has been shown for the coarser magnetites of the eastern part of the Mesabi,[6] where metamorphism has been more intense due to the proximity to the Duluth gabbro (Fig. 1).

Small magnetite metacrysts are also abundant in the somewhat schistose Soudan formation of the Vermilion Range as shown by Gruner.[7]

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[3] Leith, C. K., and Mead, W. J., *Metamorphic Geology*, p. 111, **1915.**

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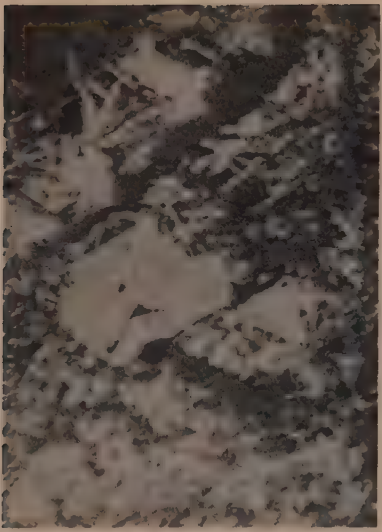

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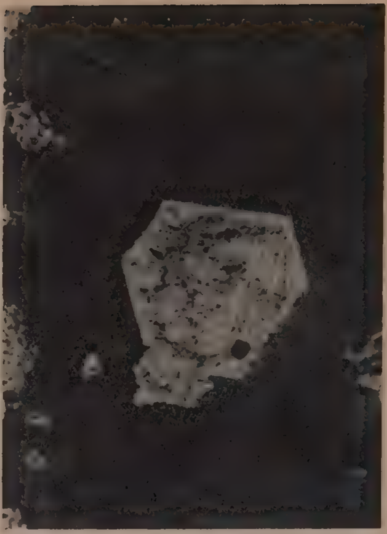

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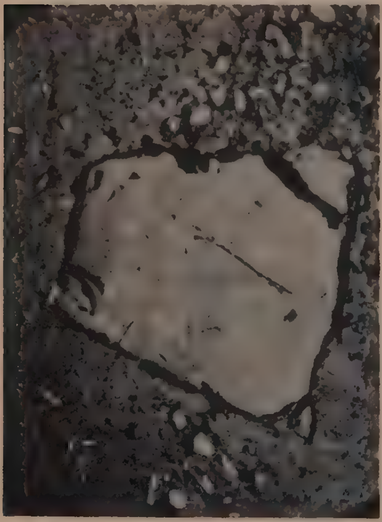

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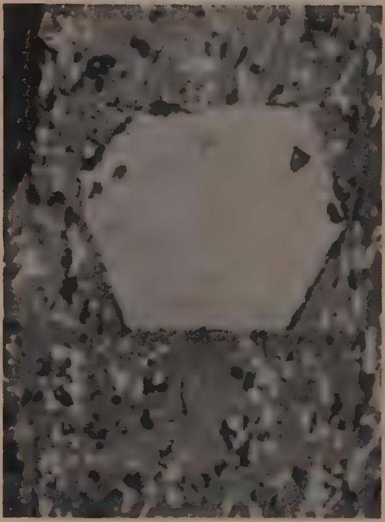

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FIG. 1. Metacryst of magnetite in taconite. Hematite needle-like forms are abundant but are cut off sharply at the contact with magnetite. East end of the Mesabi Range, Minnesota. ×200.

FIG. 2. Magnetite metacryst partly replaced by hematite (white). Holman Pit, Mesabi Range. ×134.

FIG. 3. Magnetite metacryst in garnet-chlorite schist. Small white crystals are hematite which occur equally within and without the metacryst. Michigamme Lake, Marquette district, Michigan. ×68.

FIG. 4. Magnetite metacryst in jasper. Gray is quartz and white is hematite. The orientation of the hematite indicates the schistosity. Magnetite is slightly replaced around the edge by hematite. Near Nemo, Black Hills, South Dakota. ×80.

In both the Mesabi and Vermilion districts the occurrences are usually microscopic but nevertheless magnetite forms euhedral crystals which are larger than the surrounding mineral grains.

In the Marquette iron district of Michigan near Michigamme Lake a mine dump is a classic location for collecting chlorite schist with very large garnet (andradite) metacrysts. The maximum size of the garnets is about five centimeters in diameter. This same rock shows smaller metacrysts of magnetite. These may be best observed on polished surfaces where their relations to other minerals and to each other stand out clearly. Some of the magnetite crystals are in groups or clusters and are subhedral. Others are isolated in the chlorite schist matrix and are distinctly euhedral. There are in addition to the magnetite crystals numerous lath-shaped hematite crystals. When the highly polished magnetite metacrysts are examined with the focus slightly raised shadows of the original hematite crystals may be seen as inclusions in the magnetite. Etching with concentrated HCl brings out these inclusions as shown in Fig. 3. That the iron of the metacrysts was not derived from the hematite is indicated by the fact that hematite crystals are equally abundant in and around the magnetite as elsewhere. Some of the magnetite may contain titanium, as hot concentrated HCl has a variable effect on the crystals, some being scarcely affected while others turn brown and black.

Martite octahedra up to 3 mm. have been reported in the ores near dikes in the Marquette district by Gruner.[8] It is suggested that iron for the magnetite was either introduced by solutions or gases, or was extracted by them from the basic dike material. The example cited above suggests the first explanation as more likely.

It is of interest to note that magnetite metacrysts occur included in the large garnet metacrysts with about the same distribution as in the chlorite schist portion of the rock. This suggests that the magnetite crystallized before the garnet and was included, as were the hematite crystals in the magnetite. Thus metacrysts occur within metacrysts. Specimens of chlorite schist with magnetite but lacking garnet also occur at Michigamme.

Metacrysts of magnetite seem a common feature of many ores and associated rocks in the Marquette district. A specimen of ore from Ishpeming shows good euhedral to subhedral martite metacrysts in a soft red hematite matrix. The size and distribution of the magnetite crystals indicate that the hematite may be a result of alteration of chlorite, like that described above.

Several specimens collected by Dr. John W. Gruner from the Marquette district show varied examples of the occurrence of magnetite metacrysts. A specimen of jasper from the hanging wall of the Empire Mine, near Negaunee, shows excellent small metacrysts of magnetite in quartz. The magnetite crystals range from the size of the quartz grains to excellent euhedral forms at least ten times the diameter of the small crystals. There is slight alteration to hematite.

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[8] Gruner, J. W., Additional notes on secondary concentration of Lake Superior iron ores: *Econ. Geol.*, vol. **27**, p. 200, 1932.

Samples from the 6th level of the Cliff A shaft show rather massive magnetite composed of anhedral grains varying to euhedral crystals in chlorite. So-called paint rock from the Holmes Mine shows excellent martite metacrysts, varying from subhedral to euhedral, in a hematitic and kaolinitic matrix probably derived from chloritic rock like that from the Cliff A shaft.

Ore from the contact with a dike in the Cleveland Hard Ore pit shows abundant metacrysts of magnetite in chlorite with many stages of martization. Other examples might be described but these suffice for a single district.

A chlorite-magnetite schist from Hartford County, Maryland, contains numerous metacrysts of magnetite which range up to a size with octahedral faces 5 mm. along an edge. These crystals appear perfect in a hand specimen but on polished surfaces they may be observed to vary from euhedral to subhedral, and there is much magnetite as irregular elongated masses oriented with their long dimensions parallel to the schistosity. The magnetite shows slight alteration to hematite along octahedral planes.

The iron formation of the Black Hills of South Dakota occurs at certain horizons in the exceedingly folded and metamorphosed beds of the pre-Cambrian series. At places they greatly resemble the iron formation of the Vermilion and Marquette districts of the Lake Superior region. The iron formations are exposed principally in the Nemo district which is in the northeastern part of the pre-Cambrian portion of the uplift. They are described by Darton and Paige,[9] and more recently by Runner.[10] The reader is referred to these papers for a discussion of stratigraphic relations. Runner believes that the iron formations are not limited to any one stratigraphic horizon. Within the upper series which is clearly younger than the earliest iron formation, pebbles of iron formation are found in the conglomerate.

The iron formation consists of alternating bands of recrystallized quartz and specular hematite, martite, and magnetite. In the coarser recrystallized material metacrysts of magnetite are a conspicuous feature. In some bands only a few metacrysts occur, in others the rock is closely studded with them. Polished surfaces of the various phases of the iron formations show many interesting relationships. As a rule the quartz is filled with minute plates of micaceous hematite which are usually well oriented in the direction of the schistosity (Fig. 4). Embedded in the

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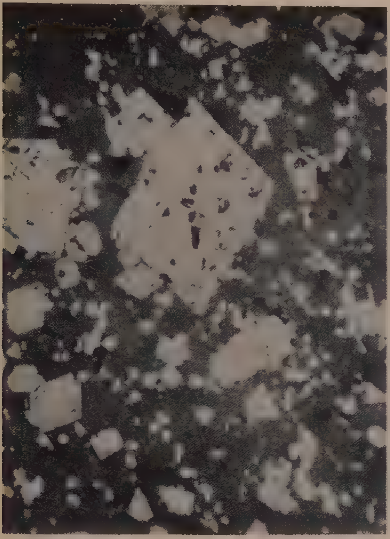
[9] Darton, N. H., and Paige, Sidney, Central Black Hills folio, South Dakota: *U. S. Geol. Survey, Geol. Atlas, Folio* **219**, 1925.

[10] Runner, J. J., Pre-Cambrian geology of the Nemo district, Black Hills, South Dakota: *Am. Jour. Sci.*, vol. **28**, pp. 353–372, 1934.



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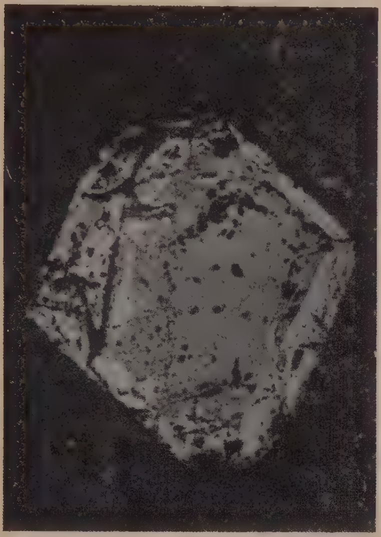

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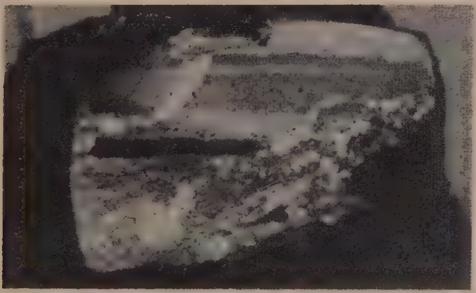

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FIG. 5. Euhedral magnetite crystals of various sizes in quartz. Near Nemo, Black Hills, South Dakota. ×80.

FIG. 6. Metacryst of magnetite altered around outside to hematite. Near Nemo, Black Hills, South Dakota. ×24.

FIG. 7. Polished surface of iron formation with bands broken and fractures filled with magnetite crystals (white). ×1½. Near Nemo, Black Hills, South Dakota.

quartz are innumerable crystals of magnetite varying from those just visible at a magnification of 100 to crystals with an octahedral face measuring 4 mm. on an edge (Fig. 5). In some specimens practically the whole range may be seen, others are more uniform. Along certain bands in the coarser recrystallized quartz the entire mass of iron oxide has crystallized to a coarse aggregate of anhedral magnetite grains. The magnetite shows all stages of alteration to hematite (martite). Figure 4, for example, shows very slight alteration along the borders and Fig. 6 a more advanced stage. Other examples were observed in which no remnants of magnetite could be seen at magnifications of 200 diameters.

The metacrysts, like those of the Marquette district, usually show no obvious source of the iron oxide, as disseminated hematite is neither more nor less abundant near the large metacrysts of magnetite. It seems clear that hematite was abundantly present during rock flowage, as it shows parallel orientation in practically all specimens. The magnetite is of later origin and the crystals cut across the schistosity with no evidence of deformation. In some specimens the original bands of the iron formation are broken and the fractures filled with magnetite grains (Fig. 7). As noted above, many of the magnetite crystals were altered to martite. Locally nearly pure hematite bands occur, but on polished surface these are observed to contain at least small metacrysts of magnetite. These hematite bands are usually decidedly schistose but the magnetite grains cut abruptly across the schistosity. Where magnetite grains make up the bulk of the specimens specular hematite often occurs as a matrix.

The above descriptions might lead one to the conclusion that magnetite metacrysts are limited to iron formations and chlorite schists. Dr. Frank F. Grout furnished the writer a muscovite schist specimen from Wardsboro, Vermont, which showed imperfectly developed magnetite metacrysts varying up to 4 mm. in diameter.

A diamond drill core of sericite schist shows excellent metacrysts about 1 mm. in diameter with minute hematite crystals oriented with the schistosity. A quartz-sericite schist also shows euhedral magnetite crystals larger than recognizable grains except original clastic quartz grains.

Harker[11] shows an excellent example of a magnetite-phyllite from Montherme, Ardenne. His interpretation is that the magnetite was present during deformation rather than having developed after rock flowage ceased.

DISCUSSION

The examples cited above, while not exhaustive, are sufficient to show that magnetite not uncommonly forms metacrysts, especially in metamorphosed iron formations and chlorite schists. The relations of these crystals to other minerals and textures in the rocks in which they occur clearly suggest their formation after orientation of hematite and chlorite in response to the forces which develop parallel orientation of minerals in metamorphic rocks.[12] The source of the iron forming some of the metacrysts is a puzzling problem. Many of the metacrysts evidently have not formed by absorbing the iron from adjacent hematite or other visible minerals. It seems rather that cases such as those illustrated by Figs. 3, 4, and 7 represent introduction of iron and oxygen. This may come from igneous emanations active during metamorphism, or equally well by transfer of iron within the rocks being metamorphosed. The latter is perhaps more difficult to explain in so far as transfer is concerned, but abundant iron is available. Magmatic solutions frequently carry iron and deposit it as magnetite as shown by the abundance of magnetite in contact metamorphic zones.

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[11] Harker, A., *Metamorphism*, p. 156, London, **1932.**

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[12] Leith, C. K., *Rock Cleavage: U. S. Geol. Survey, Bull.* **239**, p. 91, 1905.

A THIRD STUDY OF CHLORITE

A. N. Winchell, *University of Wisconsin, Madison, Wisconsin.*

In a first study of the chlorite system, published about ten years ago,[1] the chief purpose of the writer was to show that it is possible to find a definite relationship between variations in composition and variations in optic properties in the system; to do this it was necessary to understand the mode of variation in composition (and this requires a knowledge of the end-member molecules), and to use a graphic method of correlation, involving four molecules.

In a second study of chlorite published about eight years ago,[2] the correlation of variations in optic properties with variations in composition was revised in the light of the new data supplied by Orcel.[3]

At the present time the correlation needs revision once again for two reasons, first, because there are considerable additional data now available, and, second, because the diagram should be based on such numbers of molecules as will make the centerpoint of the square which represents 50 parts of the molecule at one corner plus 50 parts of that at the opposite corner, also represent, *as its equal*, 50 parts of the molecule at an adjoining corner plus 50 parts of that at its opposite corner.

To show the real increase in data it is only necessary to point out that, if only those analyses be considered which are accompanied by optic data known to be on the same material and which can be calculated into Tschermak's molecules (assuming $Fe_2O_3 = FeO$) with a maximum discrepancy of 3.0 per cent of SiO_2, there were only seven such analyses available for the first study, and only twenty-seven for the second study, while there are forty at present. Illustrating the point in a different way, in the first publication there were used eight analyses with more than 30 per cent iron molecules, in the second publication there were only six such analyses used, and in this case there are fourteen.

In order to present a diagram mathematically correct it is only necessary to use $2[H_4(Mg, Fe)_3Si_2O_9]$ at the left side and $3[H_4(Mg, Fe)_2Al_2SiO_9]$ at the right side $\{$instead of $H_4(Mg, Fe)_3Si_2O_9$ and $H_4(Mg, Fe)_2Al_2SiO_9\}$, as shown in Fig. 1. It is gratifying to find that the new data require very little change in the diagram, which differs only slightly from that published eight years ago, aside from the change due to different units at the corners of the square.

It is important to note that no claim of high accuracy is made for the diagram. It is only the best representation of existing data that the writer has been able to devise. However, it seems clear that it is approximately correct since new data lead to practically no changes.

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[1] Winchell, A. N., *Am. Jour. Sci.*, vol. **XI**, 1926, pp. 238–300.

[2] Winchell, A. N., *Am. Mineral.*, vol. **XIII**, 1928, pp. 161–170.

[3] Orcel, J., *Bull. Soc. Min. Fr.*, vol. **L**, 1927, pp. 75–456.

All the chlorites on the diagram have been plotted on the basis of the chemical analyses. The diagram gives their optic properties closely with the following exceptions.

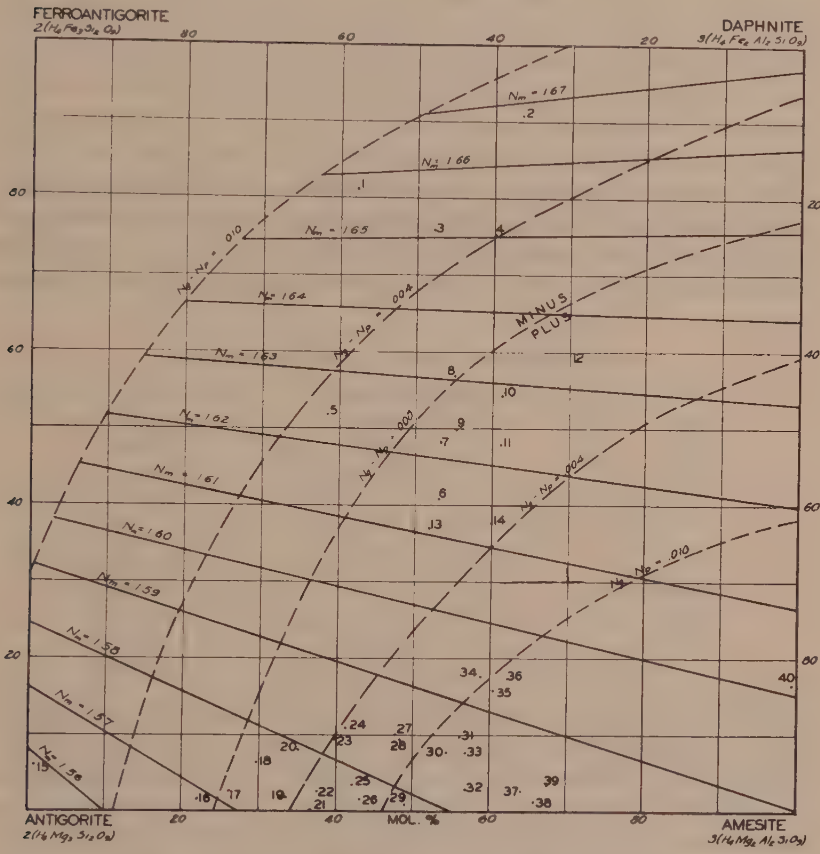

Fig. 1. Variations in composition and optic properties in the chlorite system.

The mean index of refraction is shown within ± 0.01 except in No. 1 (which is described as variable in index), No. 3 (which has N_m 0.014 too high, perhaps due to the presence of 10.56 per cent of Fe_2O_3), No. 8 (which has N_m 0.013 too high), No. 11 (which has N_m 0.062 too high perhaps due to 17.95 per cent of Fe_2O_3), No. 12 (which has been measured twice with conflicting results), No. 17 (which has N_m 0.021 too low perhaps due to 1.85 per cent of K_2O) and No. 37 (which has N_m 0.022 too low perhaps because of 14.00 per cent of H_2O).

The optic sign is correct in all cases except No. 11.

The birefringence is correct within ±0.004 except in No. 3 (which has $N_g - N_p$ 0.007 too high perhaps because of 10.56 per cent of Fe_2O_3), No. 11 (which has $N_g - N_p$ 0.012 too high perhaps because of 17.95 per cent of Fe_2O_3), and No. 24 (which has $N_g - N_p$ 0.006 too high).

As to the assumptions on which the diagram is based, it seems unnecessary to discuss further the theory of the constitution of chlorite—recent *x*-ray studies of chlorite seem to have demonstrated the validity of the theory of Tschermak. However, the writer's theory as to the variability of the state of oxidation of the iron without destruction of the crystal structure needs further study. Barnes[4] has demonstrated the possibilities of such variations in amphiboles and has shown the effects on the optic properties of these variations when produced artificially. Dschang[5] has made similar experiments on chalcodite and ripidolite with the following results:

Chalcodite, from Barenstein, Radautal, Harz

	Before heating	After heating to redness
$FeO=$	10.15	0.835
Fe_2O_3	31.16	42.66
$N_g = N_m =$	1.701	1.726

Ripidolite[6] from Wallis, Switzerland

	Before heating	After heating to redness
$FeO=$	28.07	3.16
$Fe_2O_3=$	2.42	30.0
$N_p=$	1.637	1.674
	Isotropic	Negative

Similar results (not accompanied by analyses) were obtained on penninite by Klein[7] forty years ago.

It is quite in harmony with these results to find that natural chlorites containing important quantities of ferric iron (which is assumed to be, and calculated as, ferrous iron oxidized to ferric, in nature) have higher refractive indices than appropriate for their composition. It was found by Klein that oxidation may change the optic sign from plus to minus, and that it increases the birefringence. All these effects can be found in the natural chlorites rich in ferric iron oxidized from ferrous iron. For example, the thuringite from Evisa, Corsica, (#44) has 10.56 Fe_2O_3 and $N_m = 1.665$ with $N_g - N_p = .012$, while its position on the diagram calls for $N_m = 1.65$ with $N_g - N_p = .005$. Again, the thuringite from Messina, Transvaal (#45) has 17.95 Fe_2O_3 with $N_m = 1.685$, $N_g - N_p = 0.015$, and negative sign, while the diagram calls for $N_m = 1.621$, $N_g - N_p = .003$ and positive sign.

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[4] Barnes, V. E., *Am. Mineral.*, vol. **XV**, 1930, p. 393.

[5] Pauling, L., *Proc. Nat. Acad. Sci.*, vol. **XVI**, 1930, p. 578; Mauguin, C., *C. R.*, **1928**, 186, p. 1852 and 187, p. 303; *Bull. Soc. Fr. Min.*, vol. **LIII**, 1930, p. 279; McMurchy, R. C., *Zeit. Krist.*, vol. **LXXXVIII**, 1934, p. 420.

[6] A complete analysis (before heating) was made by Dschang, *op. cit.*, p. 429.

[7] Klein, C., *N. J. Min.*, 1895, II, pp. 119–132.

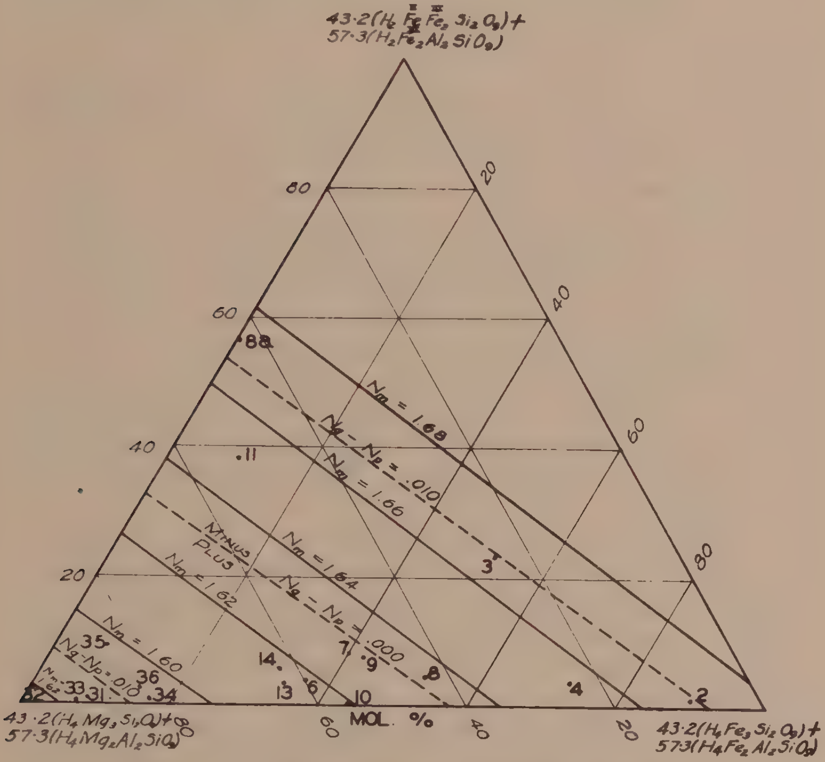

FIG. 2. Effects of oxidation of ferrous iron on the optic properties of certain chlorites.

It has been found possible to show the effects of oxidation of ferrous iron in chlorites diagrammatically—see Fig. 2. The base line of this figure corresponds with a line from a point on the base line of Fig. 1 representing about 57% of $3(H_4Mg_2Al_2SiO_9)$ to a point on the top line of Fig. 1 representing the same percentage of $3(H_4Fe_2Al_2SiO_9)$. The formulas at the lower left corner contain no iron and therefore take no part in the oxidation, which may affect the formulas at the lower right corner from

0 to 100 per cent. Accordingly, Dschang's[8] ripidolite unoxidized, belongs near the middle of the base line at 8; the same mineral, after oxidation, is found near the middle of the upper left line at 8*a:* it is evident that it has moved in a direction parallel with the upper right border. The same change has raised the refringence from 1.637 to 1.674 and the birefringence from zero to an unmeasured amount (from the diagram, about .011). Similarly, the oxidation of ferrous iron in No. 45 may be inferred to have raised the index from about 1.62 to about 1.65 (the measured value, 1.685, is inconsistent for an unknown reason) and changed the sign from plus to minus.

Diagrams for other percentages of the aluminous molecules of Fig. 1 can be prepared when sufficient data are available. It is probable from present scanty evidence that they will be similar to Fig. 2.

Dschang[9] attempts to explain the composition of iron-rich chlorites ("leptochlorites" of Tschermak) by assuming the presence of an end-member molecule, rich in silica, which he writes as follows: $H_8Mg_4Si_5O_{18}$. It is very generally agreed that one end-member molecule of the chlorite system is antigorite (or "serpentine") having the formula, $H_4Mg_3Si_2O_9$, or $H_8Mg_6Si_4O_{18}$. Dschang's proposed molecule differs from this by substituting one ion of Si for two ions of Mg. Now Mg ions have a radius of 0.75 and Si ions a radius of only about half as much, 0.40. Mg ions are surrounded by six oxygens and Si ions are surrounded by four oxygens in silica and all known silicates. Therefore a replacement of Mg by Si seems very improbable.

On very insufficient data a diagram (Fig. 3) has been prepared to show the effects of chromium on the optic properties of chlorites. In order to reduce this to three components it is necessary to assume the absence of iron. The samples used contain 1.5 to 6.5% of iron oxides. In the diagram the chlorite from Deer Park (#16) has an index which is too high for the diagram (1.59 instead of 1.575); this may be due to dehydration, as the analysis indicates a deficiency of 2.7% of H_2O. The sample from Sweden (#16a) contains 13.5% excess SiO_2; is it possible that so much quartz was present as an impurity in the sample? Chlorites containing chromium in any important amount are easily recognized by their lavender or violet color. The diagram shows plainly that as Cr replaces Al the index rises slowly, but the chief effect is a tendency to change the optic sign to minus, unless it is already minus, as in chlorites with very little alumina. As in the amesite-antigorite series, this is accomplished by decreasing the birefringence of amesite (with + sign) to zero, and then increasing it to about .005 (with − sign).

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[8] Dschang, G. L., *Chem. Erde,* vol. **VI,** 1931, p. 416.

[9] Dschang, G. L., *Chem. Erde.,* vol. **VI,** 1931, p. 434.

The chief subdivisions of the chlorite system should be defined in terms of the end-member molecules as used in Figs. 1 and 2. In the past, variety names have been used without adequate definition. Even though it involves some change in usage as compared with the definitions[10] suggested ten years ago, it seems desirable to define the varieties as indicated in the following table.

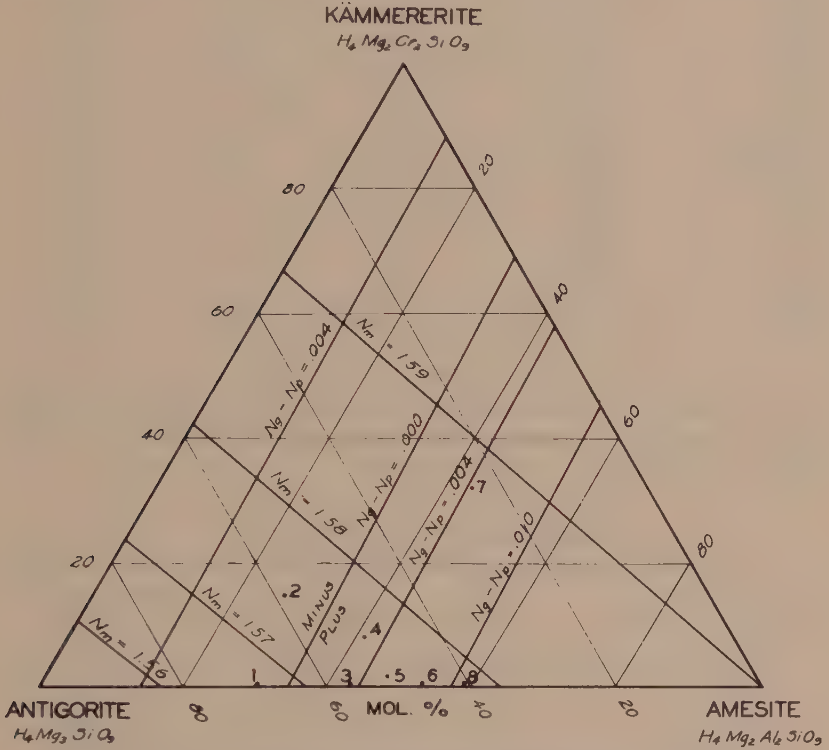

FIG. 3. Variations in composition and optic properties in the antigorite-amesite-kämmererite system.

This table includes two names (rumpfite and brunsvigite) not previously used. These types are not very common, but there is no doubt of their existence. Accurate definitions may be useful.

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[10] Winchell, A. N., *Am. Jour. Sci.*, vol. **XI**, 1926, p. 294.

CHEMICAL CLASSIFICATION OF THE CHLORITE SYSTEM

Names	%(3At+3Dn)	%(2Ant +2FeAnt)	%(2FeAnt +3Dn)	%(2Ant+3At)
Antigorite	0–20	100–80	0–20	100–80
Jenkinsite	0–20	100–80	20–40	80–60
Penninite	20–40	80–60	0–20	100–80
Delessite	20–40	80–60	20–40	80–60
Clinochlore	40–60	60–40	0–20	100–80
Rumpfite	40–60	60–40	20–40	80–60
Diabantite	40–60	60–40	40–60	60–40
Brunsvigite	40–60	60–40	60–80	20–40
Corundophilite	60–80	40–20	0–20	100–80
Prochlorite	60–80	40–20	20–40	80–60
Ripidolite	60–80	40–20	40–60	60–40
Aphrosiderite	60–80	40–20	60–80	40–20
Thuringite	60–80	40–20	80–100	20–0
Amesite	80–100	20–0	0–20	100–80
Daphnite	80–100	20–0	80–100	20–0

For convenience in petrographic work a classification based on optic properties may be useful. As modified by the two new terms just suggested, it is as follows:

OPTIC CLASSIFICATION OF THE CHLORITE SYSTEM

Names	Sign	N_m	N_g-N_p
Antigorite	−	1.55–1.58	0.004–0.010
Jenkinsite	−	1.58–1.61	0.004–0.010
−Penninite	−	1.56–1.59	0.000–0.004
Delessite	−	1.59–1.61	0.000–0.004
Diabantite	−	1.61–1.63	0.000–0.004
Aphrosiderite	−	1.63–1.65	0.000–0.004
Daphnite	−	1.65–1.67	0.000–0.004
Brunsvigite	−	1.63–1.65	0.004–0.010
Thuringite	−	1.65–1.68	0.004–0.010
+Penninite	+	1.57–1.61	0.000–0.004
Rumpfite	+	1.61–1.63	0.000–0.004
Ripidolite	+	1.63–1.65	0.000–0.004
Clinochlore	+	1.57–1.59	0.004–0.010
Prochlorite	+	1.59–1.62	0.004–0.010
Amesite	+	1.58–1.61	0.010–0.015+

These two classifications of chlorite are only roughly equivalent. The relations between them are shown in Fig. 4.

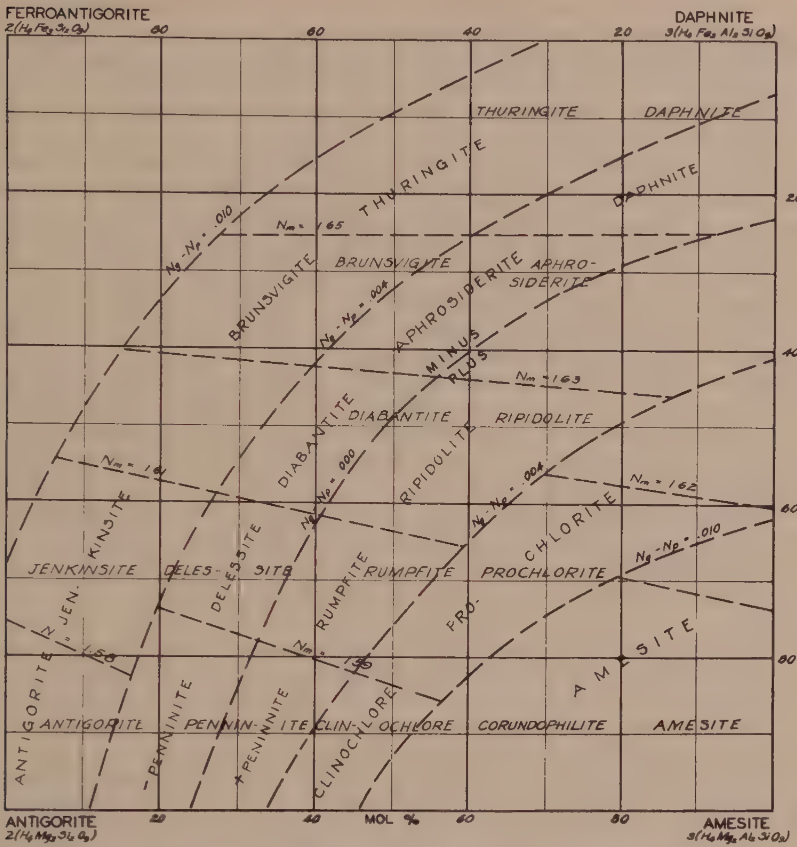

FIG. 4. Chemical and optical classifications of the chlorite system.

REFERENCES AND OPTIC DATA FOR FIGS. 1 AND 2

1. "Thuringite," Creede, Colo. Larsen, E. S. and Steiger, G.: *Jour. Wash. Acad. Sci.*, vol. **VII**, 1917, p. 7. (−) $2V$ = moderate. $N_m = 1.637$ (variable), $N_g - N_p = .01\pm$.

2. "Bavalite," Bas-Vallon, France. Orcel, J.: *Bull. Soc. Fr. Min.*, vol. **L**, 1925, pp. 245–248; Orcel's analysis 128, (−) $2V$ = very small. $N_g = N_m = 1.667$ (calc. from $N_g - N_p$), $N_p = 1.658$, $N_g - N_p = .009$.

3. "Thuringite," Evisa, Corsica. Orcel, J.: *Op. cit.*, pp. 254–262; Orcel's analysis 25. (−) $2V = ?$ $N_g = N_m = 1.665$, $N_p = 1.653$, $N_g - N_p = .012$.

4. "Aphrosiderite," Weilburg, Nassau. Orcel, J.: *Op. cit.*, pp. 250–262; Orcel's analysis 123, (−) $2V = ?$ $N_g = N_m = 1.651$, $N_p = 1.648$; $N_g - N_p = .003 - .004$.

5. "Diabantite," Westfield, Mass. Shannon, E. V.: *U. S. Nat. Mus. Proc.*, vol. **LVII**, 1920, p. 397. (−) $2V = 0°$, $\pm N = 1.62\pm$.

6. "Ripidolite," Isère, France. Orcel, J.: *Op. cit.*, pp. 229–231; Orcel's analysis 95. (+) $2V$ = very small. $N_g = 1.620$, $N_m = N_p = 1.616$, $N_g = N_p = .004$.

7. "Ripidolite," Masoala, Madagascar. Orcel, J.: *Op. cit.*, pp. 237–239; Orcel's analysis 82. (+) $2V = ?$ $N_g = 1.634$, $N_m = N_p = 1.633$, $N_g - N_p = .001$.

8. "Ripidolite," Wallis, Switzerland. Dschang, G. L.: *Chem. Erde,* vol. **VI,** 1931, p. 416. Isotropic with $N=1.637$; 8*a*, same after oxidation: $(-)\ 2V=?$, $N_p=1.674$.

9. "Ripidolite," Laifour, Ardennes, France. Orcel, J.: *Op. cit.*, pp. 232–237; Orcel's analysis 81. $(+)\ 2V=0°\pm$, $N_g=1.638$, $N_m=N_p=1.637$, $N_g-N_p=.001$.

10. Chlorite, Shoshone Co., Idaho. Shannon, E. V.: *U. S. Nat. Mus., Bull.* **131,** 1926, p. 378. $(+)\ 2V=0°\pm$, $N_g=1.635$, $N_m=N_p=1.630$, $N_g-N_p=.005$.

11. "Thuringite," Messina, Transvaal. Orcel, J.: *Op. cit.*, pp. 262–266. Orcel's analysis 9. $(-)\ 2V=0°\pm$, $N_g=N_m=1.685$, $N_p=1.670$, $N_g-N_p=.015$. These data do not check the diagram, perhaps due in part to the presence of 17.95 Fe_2O_3.

12. "Aphrosiderite," Field, Brit. Col. Larsen, E. S. and Steiger, G.: *Jour. Wash. Acad. Sci.*, vol. **VII,** 1917, p. 6. $N_m=1.623$, $N_g-N_p=$ very low. Optics also by Orcel: *Op. cit.*, pp. 360 and 415. $(+)\ 2V=?$, $N_g=1.610$, $N_m=N_p=1.606$, $N_g-N_p=.004$.

13. "Ripidolite," Androta, Madagascar. Orcel, J.: *Op. cit.*, pp. 227–229. Orcel's analysis 93. $(+)\ 2V=0°$. $N_g=1.621$, $N_m=N_p=1.618$, $N_g-N_p=.003$.

14. "Prochlorite," Waterworks tunnel, D. C. Analysis by F. W. Clark and E. A. Schneider, *U. S. Geol. Surv., Bull.* **78,** 1891. p. 19. Optic data by E. S. Larsen (*U. S. Geol. Surv., Bull.* **679,** 1920, p. 123): $(+)\ 2V=$ small, $N_m=1.605$, $N_g-N_p=$ weak. Optic data also by E. V. Shannon: *U. S. Nat. Mus., Proc.* **LVIII,** 1920, p. 475: $(+)\ 2V=0°\pm$, $N_g=1.610$, $N_m=N_p=1.606$, $N_g-N_p=.006$.

15. "Antigorite," Muruhatten, Sweden. Du Rietz, T.: *Geol. För. Förh. Stockholm,* vol. **LVII,** 1935, p. 133. $N_g=1.570\pm.002$, $N_p=1.564$; $N_g-N_p=.006-.009$.

16. "Colerainite," Nottingham, Pa. Shannon, E. V. and Wherry, E. T.: *Jour. Wash. Acad. Sci.*, vol. **XII,** 1922, p. 239. $(-)\ 2E=30°$, $N_g=N_m=1.560$, $N_p=1.555$, $N_g-N_p=.005$.

17. "Pennine," Recess, Ireland. Hutchinson, A. and Smith, W. C.: *Mineral. Mag.*, vol. **XVI,** 1912, p. 264. $(+)\ 2V=0°\pm$, $N_m=1.551$.

18. "Pennine," locality? Dschang, G. L.: *Chem. Erde,* vol. **VI,** 1931, p. 416. $(+)\ 2V=?$, "$N_g=?$ $N_m=1.567$, $N_p=1.5655$," [but record probably should be: $N_g=1.567$, $N_m=N_p=1.5655$—A. N. W.]

19. "Leuchtenbergite," No. Korea. Sato, S.: *Jour. Shanghai Sci. Inst.*, vol. **I,** 1933, p. 17. $(+)\ 2V=0°$, "$N_g=N_m=1.575$, $N_p=1.571$, $N_g-N_p=.004$," but record should be: $N_g=1.575$, $N_m=N_p=1.571$, since the mineral is positive.

20. "Leuchtenbergite, Urals. Dschang, G. L.: *Chem. Erde,* vol. **VI,** 1931, p. 416. $(+)\ 2V=0°\pm$, "$N_g=?$, $N_m=1.5760$, $N_p=1.5705$," [but record probably should be: $N_g=1.576$, $N_m=N_p=1.5705$—A. N. W.]

21. "Leuchtenbergite," Phillipsburg, Mont. Shannon, E. V. (and Ross, C. S.): *Am. Mineral.*, **VIII,** 1923, p. 8. $(+)\ 2V=6°-14°$, $N_g=1.575$, $N_m=N_p=1.572$, $N_g-N_p=.003$.

22. "Clinochlore," Togoland. Orcel, J.: *Op. cit.*, pp. 267–271; Orcel's analysis 272. $(+)\ 2V=0°\pm$, $N_g=1.576$, $N_m=N_p=1.571$, $N_g-N_p=.0053$.

23. "Clinochlore," West Town, Pa. Dschang, G. L.: *Chem. Erde.*, vol. **VI,** 1931, p. 416. $(+)\ 2V=0°\pm$, "$N_m=1.5755$, $N_p=1.5715$," [but record probably should be: $N_g=1.5755$, $N_m=N_p=1.5715$—A. N. W.]

24. "Chlinochlore," Besofotra, Madagascar. Orcel, J.: *Op. cit.*, pp. 266–267. Orcel's analysis 170. $(+)\ 2V=0°\pm$, $N_g=1.594$, $N_m=N_p=1.584$, $N_g-N_p=.010$.

25. Chlorite, Mt. Ampanobe, Madagascar. Lacroix, A.: *Mineral. Madagascar,* vol. **II,** p. 544. Optics by J. Orcel: *Op. cit.*, p. 414. $(+)\ 2V=0°\pm$, $N_g=1.588$, $N_m=N_p=1.578$, $N_g-N_p=.010$.

26. "Leuchtenbergite," Korea. Kinosaki, Y.: *Bull. Mineral. Survey Chosen,* vol. **VII,** 1932, No. 1; *Min. Abst.*, vol. **V,** p. 421. $(+)\ 2V=$ small, $N_g=1.576$, $N_m=N_p=1.5715$, $N_g=N_p=.0045$.

27. "Prochlorite," Modena, Italy, Gallitelli, P.: *Min. Abst.*, vol. **IV**, 1930, p. 470. $N=1.58$.

28. "Prochlorite," Ambatofinandrahana. Orcel, J.: *Op. cit.*, pp. 199–202; Orcel's analysis 71. (+) $2V=29^\circ$, $N_g=1.5939$, $N_m=1.5887$, $N_p=1.5580$, $N_g-N_p=.0109$.

29. "Leuchtenbergite," Midongy, Madagascar. Orcel, J.: *Op. cit.*, pp. 196–199; Orcel's analysis 47. (+) $2V=18^\circ-19^\circ$, $N_g=1.5904$, $N_m=1.5754$, $N_p=1.5749$, $N_g-N_p=.015$.

30. "Grochauite," Kaslinski, Urals. St. Pavlovitch: *Min. Abst.*, vol. **V**, 1933. p. 215. $N_g=1.597$, $N_m=1.593$, $N_p=1.587$, $N_g-N_p=0.010$. [N_m probably too high, since the mineral is probably positive with small optic angle—A. N. W.]

31. "Prochlorite," Madison Co. N. C. Orcel, J.: *Op. cit.*, pp. 207–208 and 415. (+) $2V=0^\circ\pm$, $N_g=1.596$, $N_m=N_p=1.588$, $N_g-N_p=.008$.

32. "Sheridanite," Miles City, Mont. Shannon, E. V. and Wherry, E. T.: *Jour. Wash. Acad. Sci.*, vol. **XII**, 1922, p. 329. (+) $2E=$small, $N_g=1.589$, $N_m=N_p=1.576$, $N_g-N_p=.013$.

33. "Prochlorite," Madison Co., N. C. Orcel, J.: *Op. cit.*, pp. 205–206. Orcel's analysis 57. (+) $2V=19^\circ$, $N_g=1.600$, $N_m=?$, $N_p=1.588$, $N_g-N_p=.012$.

34. "Prochlorite," Rainbow Camp, Transvaal. Orcel, J.: *Op. cit.*, pp. 214–216. Orcel's analysis 68. (+) $2V=$small, $N_g=1.602$, $N_m=N_p=1.593$, $N_g-N_p=.009$.

35. "Clinochlore," Achmatowsk. Dschang, G. L.: *Chem. Erde.*, vol. **VI**, 1931, p. 416. (+) $2V=?$, "$N_g=?$, $N_m=1.5975$, $N_p=1.588$," [but the record probably should be: $N_g=1.5975$, $N_m=N_p=1.588$, $N_g-N_p=.0095$—A. N. W.]

36. "Grochauite," Antohidrano, Madagascar. Orcel, J.: *Op. cit.*, pp. 217–220. Orcel's analysis 67. Optics given on p. 217: (+) $2E=40^\circ$, $N_g=1.606$, $N_m=N_p=1.594$, $N_g-N_p=.012$. Optics given on p. 415. $N_g=1.596$, $N_m=N_p=1.584$, $N_g-N_p=.012$.

37. "Colerainite," Brinton's Quarry, Pa., Shannon, E. V. and Wherry, E. T.: *Jour. Wash. Acad. Sci.*, vol. **XII**, 1922, p. 239. (+) $2V=0^\circ$, $N_g=1.576$, $N_m=N_p=1.562$, $N_g-N_p=.014$.

38. "Sheridanite," Sheridan Co., Wyo. Wolff, J. E.: *Am. Jour. Sci.*, vol. **XXXIV**, 1912, p. 475. (+) $2E=26^\circ-50^\circ$, $N_g=1.589$, $N_m=1.580-1.581$, $N_p=1.580$, $N_g-N_p=.009$.

39. "Sheridanite," Comberousse, France. Orcel, J.: *Op. cit.*, pp. 189–195. Orcel's analysis 31. (+) $2E=20^\circ\pm$, $N_g=1.586$, $N_m=1.580$, $N_p=1.578$; also, on p. 414, $N_g=1.588$, $N_m=1.581$, $N_p=1.580$, $N_g-N_p=.008$.

40. "Amesite," Chester, Mass. Shannon, E. V.: *Am. Jour. Sci.*, vol. **XLIX**, 1920, p. 96. (+) $2V=0^\circ\pm$, $N_g=1.612$, $N_m=N_p=1.597$, $N_g-N_p=.015$.

REFERENCES AND OPTIC DATA FOR FIG. 3

1. =16 of preceding list.

2. Chlorite, Deer Park, Wyo. Shannon, E. V.: *U. S. Nat. Mus. Proc.*, vol. **LVIII**, 1920, p. 378. (−) $2V=0^\circ\pm$, $N_g=N_m=1.590$, $N_p=1.587$, $N_g-N_p=.003$.

3. =19 of preceding list.

4. Chlorite, Togoland, Orcel, J.: *Op. cit.*, pp. 267–271. Orcel's analysis 271. (+) $2V=0^\circ\pm$, $N_g=1.584$, $N_m=N_p=1.579$, $N_g-N_p=.005$.

5. =22 of preceding list.

6. =26 of preceding list.

7. "Kämmererite," Säkok Ruopsok, Sweden. Du Rietz, T.: *Geol. För. Förh. Stockholm*, vol. **LVII**, 1935, p. 133. (+) $2V=$small, $N_g=1{,}590$, $N_m=?$, $N_p=1.586$, $N_g-N_p=.004$.

8. =29 of preceding list.

9. =38 of preceding list.

BABINGTONITE AND EPIDOTE FROM WESTFIELD, MASSACHUSETTS

CHARLES PALACHE, *Harvard University, Cambridge, Massachusetts*

In 1932 I read a paper on babingtonite before the Mineralogical Society[1] describing several new occurrences of this rare mineral. Concerning one of these, Holyoke, Mass., I stated "In abundance and beauty it far surpasses any previously described occurrence of babingtonite." This statement is no longer true, at least as regards the beauty of specimens, since the babingtonite from Westfield, Mass., far surpasses that of Holyoke in attractiveness.

A group of students of mineralogy from Harvard University, visiting the well-known trap quarry at Westfield in the spring of 1935, brought back a number of specimens which proved to contain babingtonite, hitherto not reported from this locality.[2] The specimens consist of veins in the diabase, narrow for the most part but expanding to a width of three or four inches. The veins appear, from the hand specimens collected, to be of no great lateral extent and vary widely in paragenesis as revealed by the following partial list of mineral sequences.

Quartz, calcite
Calcite only
Datolite only
Calcite, datolite, apophyllite
Quartz, chlorite, calcite, prehnite
Quartz, chlorite, epidote (iron-rich), prehnite
Calcite, epidote (iron-poor), datolite
Quartz, chlorite, sphalerite, chalcopyrite, calcite
Chlorite, calcite, babingtonite
Calcite, babingtonite
Quartz, prehnite, babingtonite, calcite
Ring structures, epidote, datolite, epidote, prehnite, datolite

It is clear from this list that the sequence generally begins with either quartz or calcite, and calcite is the most abundant mineral, in many cases completely filling the vein in coarse granular aggregates. All the minerals present except datolite being little attacked by acid, it was possible to remove the calcite with dilute hydrochloric acid, thus revealing the earlier minerals.

The most striking specimen, shown in the photograph, is a vein section about nine inches square. After treatment with acid it showed a thin wall-coating of granular quartz upon which rests prehnite of a rich green color, coarsely crystallized in rudely cone-shaped aggregates an inch across. Upon the prehnite the babingtonite stands in clusters of rough crystals, velvety black in color and measuring from a half to three-quarters of an inch in diameter. The color contrast produces a specimen of most uncommon beauty.

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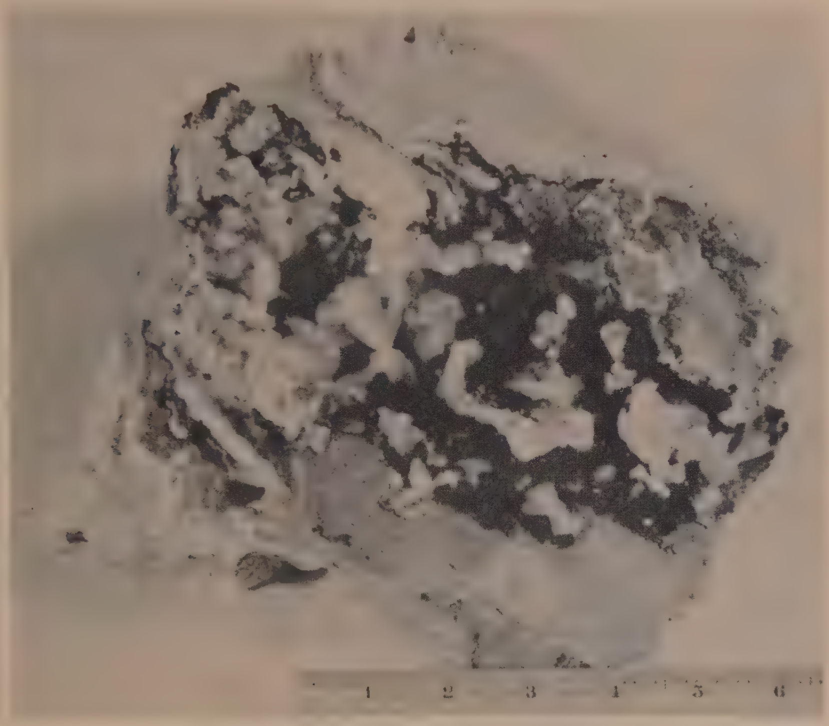
[1] Palache, C., and Gonyer, F. A., On babingtonite: *Am. Mineral.*, vol. **17**, p. 295, 1932.

[2] Shannon, Earl V., Famous mineral localities. The datolite locality near Westfield, Mass.; *Am. Mineral.*, vol. **4**, p. 5, 1919.



Babingtonite and Prehnite from Westfield, Massachusetts

The babingtonite crystals are curved and indistinct, but a study of some of the smaller ones by Mr. W. E. Richmond, Jr. established the presence of the forms:—$c(001)$, $b(010)$, $a(100)$, $h(110)$, $g(2\bar{1}0)$, $f(3\bar{2}0)$, $o(011)$, $s(0\bar{1}1)$, and $d(101)$, all known from the Holyoke specimens and in similar development.[3]

Analysis of a sample of very fresh crystals by F. A. Gonyer yielded the composition of column 1.

[3] *Loc. cit.*, p. 297 and Fig. 3.

Analysis of Babingtonite

	1.	2.
SiO_2	52.32	52.44
TiO_2	0.15	abs.
Al_2O_3	0.95	0.23
Fe_2O_3	13.42	14.43
FeO	10.65	10.12
MnO	0.31	1.03
MgO	0.50	0.65
CaO	19.88	19.67
Na_2O	0.27	0.08
K_2O	abs.	abs.
H_2O+	1.36	1.27
	99.81	99.82

1. Westfield, Mass., Analyst, F. A. Gonyer
2. Holyoke, Mass., Analyst, F. A. Gonyer

Comparison of the two analyses shows how closely the two occurrences conform in chemical nature. Once more we have strong evidence of the essential constancy in composition of this complex silicate.[4]

The associated minerals except epidote present little that is noteworthy. The chlorite, sparsely present in a few specimens, is in the form of bronzy scales. It is probably the same chlorite as described by Shannon[5] under the name chalcodite.

Datolite is in part massive, in part in water-white, glassy crystals of great complexity of development.

Epidote is in two generations, but as they do not occur together their relative age is unknown. The one is of an ordinary yellowish green color and shows no distinctive features. The other is deep black in color, simulating babingtonite closely. This epidote was analyzed by Mr. Gonyer and studied optically by Dr. Berman, to whom I am indebted for the data presented below.

Analysis of Epidote from Westfield, Mass.

SiO_2	36.52
TiO_2	abs.
Al_2O_3	20.97
Fe_2O_3	17.22
FeO	0.45
MnO	abs.
MgO	abs.
CaO	23.05
H_2O+	1.98
	100.19

D. = 3.49 (Berman)

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[4] *Loc. cit.*, p. 299.

[5] Shannon, E. V., Diabantite, stilpnomelane and chalcodite from Westfield: *Proc. United States Nat. Mus.*, **57**, p. 397, 1920.

Discussion of the analysis yields the formula:

$$Ca_2(Al, Fe)_3Si_3O_{12}(OH) \text{ with } Al/Fe = 1.91$$

The optical data obtained by Dr. Berman are:—$\alpha = 1.751$, $\beta = 1.784$, $\gamma = 1.797$; all $\pm .002$. $Bx\ (-)$, $2V = 64° \pm 2°$, $r > v$. X = colorless; Y = green; Z = olive green.

As this epidote is high in iron, an attempt was made to determine how it would modify the published curves relating iron content and refractive indices. It was found, however, that the data in this region of the curve were too few and too contradictory to permit the drawing of a curve with any real meaning. It is evident that more data obtained from analyzed material are necessary not only in the iron-rich epidotes but throughout the series.

A NEW PHOSPHATE, BERMANITE, OCCURRING WITH TRIPLITE IN ARIZONA

CORNELIUS S. HURLBUT, JR., *Harvard University, Cambridge, Massachusetts*

In 1929, R. M. Wilke sent to the Department of Mineralogy at Harvard University a suite of mineral specimens collected near the Bagdad Copper Mine, about 25 miles west of Hillside, Arizona. In 1931 the writer visited the locality and several others nearby, and made a more complete collection.

TRIPLITE

The original material came from a nearly spherical segregation about two feet in diameter within a pegmatite knot located on the 7 U 7 Ranch. The pegmatite is lens shaped, about 20 feet in maximum dimension, and composed dominantly of milky quartz with some orthoclase and muscovite. It appears to be completely inclosed within a coarse-grained granite. Triplite makes up the bulk of the segregation, but along fractures in it secondary minerals have been deposited. Considering its limited volume, the triplite is coarsely crystalline with single cleavage fragments measuring as much as six inches across. Only small amounts are fresh with a pinkish brown color and resinous luster, and much of it is a shiny black due to oxidation of the manganese.

At three other locations, all within a radius of seven miles, triplite was found as the chief constituent of similar segregations within pegmatite knots. The largest pegmatite forms a hill about 100 feet in diameter and 50 feet high. Triplite was found here in a small pocket near the top of the hill associated with a green mica and fluorite. At the two remaining localities, one at the base of Mt. Loma and the other in "the granites," triplite was the only mineral found in addition to the ordinary pegmatite minerals. The optical properties showed the triplite from these three localities to be the same, but different from that at the 7 U 7 Ranch. Accordingly, chemical analyses were made of triplite from the 7 U 7 Ranch and from Mt. Loma.

The triplite from Mt. Loma has a ratio of Fe:Mn = 1:8 and is thus similar to that from Branchville, Conn., as given in Dana.[1] That from the 7 U 7 Ranch differs from any hitherto reported, with a ratio of Fe:Mn:Mg = 1:3:2. The optical properties reflect this difference, and show not only lower indices of refraction, but a wholly different optical orientation.

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[1] Dana, E. S., *System of Mineralogy*, 6th ed., New York, **1892.**

ANALYSES OF TRIPLITE BY F. A. GONYER

	I	II
Fe_2O_3	—	0.40
FeO	11.68	6.68
MnO	34.55	53.77
MgO	11.87	0.31
CaO	2.48	2.17
Na_2O	0.52	—
H_2O	0.75	—
P_2O_5	33.32	32.20
F	8.02	7.58
	103.19	103.11
Less 0	3.38	3.19
	99.81	99.92

I. Triplite from the 7 U 7 Rranch
II. Triplite from Mt. Loma

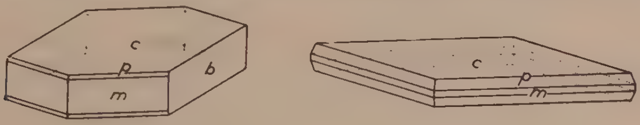
OPTICAL PROPERTIES OF ARIZONA TRIPLITE

I		II	
$\alpha=1.651$	Opt. (+)	$\alpha=1.662$	Opt. (−)
$\beta=1.653$	$2V=28°$	$\beta=1.673$	$2V=88°$
$\gamma=1.665$	$r>v$ str.	$\gamma=1.684$	$r>v$
$X=b$	$Z\wedge a=22°$	$Y=b$	$Z\wedge a=42°$

I. Triplite from the 7 U 7 Ranch
II. Triplite from Mt. Loma

BERMANITE

In narrow veinlets crossing the triplite at the 7 U 7 Ranch is a reddish brown mineral that is found in small crystals where the veins open into narrow vugs. This proved to be a new species and is called bermanite. In addition to the bermanite, six other minerals are present on the walls of the cavities, of which only one, torbernite, in small green pseudocubes, could be identified. Four of the minerals are present as tiny brilliantly colored crystals in amounts barely sufficient to determine their optical properties, while the remaining one forms in thin white crusts.



1 2

FIGS. 1 and 2. Bermanite.

Bermanite is orthorhombic with a pronounced tabular habit. The largest crystals are several millimeters across, and most of them are arranged in subparallel aggregates with a fan-shaped or rosette-like appearance. Figure 1 shows the characteristic form of the larger crystals with the base, prism and brachypinacoid dominant. Only crystals under 0.5 mm. in maximum dimension proved to be single individuals, and consequently goniometric measurements were confined to crystals below that size. These smaller crystals differ from the larger ones in habit; (010) is rarely present, and (111) is a prominent form as shown in Fig. 2.

TABLE 1

BERMANITE. TWO-CIRCLE MEASUREMENTS ON TEN CRYSTALS

Forms	Faces	Measured Range		Measured Mean		Calculated	
		ϕ	ρ	ϕ	ρ	ϕ	ρ
c(001)	10			—	0°00′	—	0°00′
b(010)	4	0°01′– 0°13′	89°56′–90°05′	0°06′	90 00	0°00′	90 00
m(110)	10	55°20′–55°31′	89 50 –90 05	55 27	89 59	55 26	90 00
r(116)	3	55 28 –55 36	32 20 –32 23	55 31	32 22	55 26	32 53½
n(113)	7	54 58 –55 45	51 39 –52 40	55 28	52 18	55 26	52 17½
o(112)	5	54 21 –54 36	62 22 –62 49	55 22	62 35	55 26	62 44
p(111)	24	54 41 –56 19	74 47 –75 42	55 25	75 33	55 26	75 33

TABLE 2

BERMANITE—$(Mn'', Mg)_5Mn_8'''(PO_4)_8(OH)_{10}\cdot 15H_2O$

Orthorhombic; dipyramidal—$2/m\ 2/m\ 2/m$

$a:b:c=0.6890:1:2.2018$; $p_0:q_0:r_0=3.1956:2.2018:1$

$q_1:r_1:p_1=0.6890:0.3038:1$; $r_2:p_2:q_2=0.4542:1.4514:1$

Forms	ϕ	$\rho=C$	ϕ_1	$\rho_1=A$	ϕ_2	$\rho_2=B$
c(001)	—	0°00′	0°00′	90°00′	90°00′	90°00′
b(010)	0°00′	90 00	90 00	90 00	—	0 00
m(110)	55 26	90 00	90 00	34 34	0 00	55 26
r(116)	55 26	32 53½	20 09	63 26	61 57½	72 03
n(113)	55 26	52 17½	36 16½	49 21	43 11½	63 19½
o(112)	55 26	62 44	47 45	42 57	32 02½	59 43
p(111)	55 26	75 33	65 34½	37 07	17 22½	56 40½

Ten crystals were measured, each of which had one dominant face with the pyramid faces truncating it symmetrically. This best-developed face was taken as the basal pinacoid, thereby fixing the position of the crystallographic axes.

A reasonable agreement between the measured and calculated position angles of the various forms is shown in Table 1. The pyramid *r* was found only on one crystal as line faces and its measurements are consequently less satisfactory. Aside from the basal pinacoid the steep pyramid (111) is the most prominent form. The prism zone is poorly developed in the small measured crystals, with (110) present only as line faces, and (010) only as points.

X-Ray Measurements:—Rotation photographs were taken about the three crystallographic axes. The dimensions of the unit cell thus obtained are:

$$a_0=6.25\text{Å},\ b_0=8.92\text{Å},\ c_0=19.61\text{Å}$$

which give the ratio:

$$a_0:b_0:c_0=0.701:1:2.198.$$

This ratio is in fair agreement with the morphological axial ratio: $a:b:c=0.6890:1:2.2018$.

Physical and Optical Properties:—The cleavage of bermanite is perfect parallel to (001), and imperfect parallel to (110). The hardness is 3.5. The specific gravity is 2.84 determined by suspension in bromoform. The color is a reddish brown, somewhat darker on exposed surfaces. The optical properties determined by the immersion method are as follows:

$$\begin{array}{l} X=c\text{-axis}\\ Z=a\text{-axis}\\ \ \end{array} \qquad \left.\begin{array}{l}\alpha=1.687\\ \beta=1.725\\ \gamma=1.748\end{array}\right\}\pm0.003 \qquad \begin{array}{l}\text{Negative}\\ 2V=74^\circ\\ r<v\end{array}$$

Pleochroism: X = light red, Y = pale yellow, Z = deep red.

Chemical composition: The following analysis of bermanite yields the formula: $R_5''R_8'''(PO_4)_8(OH)_{10}\cdot 15H_2O$, where

$$R'''=Mn:Fe=9:1$$
$$R''=Mn:Mg:(Ca+Na)=19:6:2$$

Analysis of Bermanite by F. A. Gonyer

Fe_2O_3	3.03%
Mn_2O_3	28.76
MnO	13.79
MgO	2.39
CaO	0.72
Na_2O	0.32
H_2O	19.33
P_2O_5	31.39
	99.73

The molecular weight of the unit cell (M) was determined by use of the formula, $M=\frac{Vd}{A}$, where V is the volume of the unit cell (1094×10^{-24} c.c.), d is the density (2.84 gm/c.c.) and A is the reciprocal of Avagadro's number (1.65×10^{-24}). The value for M is 1883. The number of atoms in the unit cell was determined by the use of M, and is listed below with the percentage weights of the chemical analysis reduced to 100 per cent.

	Per cent	*Molecular ratio*		*Atomic ratio*	*Atoms/ unit cell*	
Fe_2O_3	3.04	0.0190	Fe	0.0380	0.72	7.58
Mn_2O_3	28.84	0.1822	Mn	0.3644	6.86	
MnO	13.82	0.1944	Mn	0.1944	3.66	5.22
MgO	2.40	0.0593	Mg	0.0593	1.12	
CaO	0.72	0.0128	Ca	0.0128	0.24	
Na_2O	0.32	0.0052	Na	0.0104	0.20	
H_2O	19.38	1.0730	H	2.1460	40.41	40.41
P_2O_5	31.48	0.2210	P	0.4420	8.32	8.32
	100.00					

If it is assumed that the numbers in the last column represent the integers 8, 5, 40, and 8, respectively, the composition of the unit cell is:

$$R_5''R_8'''(PO_4)_8(OH)_{10}\cdot 15H_2O.$$

Pyrognostics:—On charcoal before the blowpipe bermanite first swells and separates into scales, and then fuses easily to a globule. With borax an amethystine bead is given in the oxidizing flame, that becomes colorless in the reducing flame. A bluish green bead is given with soda. Bermanite swells in the closed tube and yields abundant neutral water. It is soluble in nitric acid and forms a yellow precipitate with ammonium molybdate.

In view of the many contributions to the science of mineralogy by Dr. Harry Berman, it seems fitting to name this new species bermanite in his honor.

UNIDENTIFIED PHOSPHATES

Qualitative chemical tests show all five of the unidentified minerals that occur with bermanite at the 7 U 7 Ranch to be phosphates. Inasmuch as four of them are found only in isolated crystals, it is difficult to establish a definite sequence of deposition. In the following brief description, however, they will be referred to by number in the order in which it is believed they were deposited.

Number 1 is present in bright blue grains surrounded by a lighter blue area several millimeters in diameter. Its alteration is believed to account for the staining of the surrounding cavity wall.

Number 2 is a light brown mineral, more abundant than any of the others, and frequently shows crystal outlines. An attempt to measure it on the goniometer, although not entirely successful, indicated it is orthorhombic with the forms (001), (111), and (110) present. Parallel extinction against the cleavage faces also pointed to orthorhombic symmetry.

Number 3 is purple, and occurs in rounded grains that show an occasional crystal face.

Number 4 is a wine-colored mineral that is found in small amounts as minute tabular crystals.

Bermanite follows number 4 in the sequence of deposition, and no doubt thick crusts of it in many places obscure the earlier minerals.

Number 6 forms thin white crusts that cover the earlier minerals. It is soft and has much the appearance of gypsum.

Optical Properties of Unidentified Phosphates

	1	2	3	4	6
Indices	$\alpha=1.690$	$\alpha=1.591$	$\omega=1.740$	$\alpha=1.706$	$\alpha=1.642$
	$\beta=1.720$	$\beta=1.615$	$\epsilon=1.763$	$\beta=1.718$	$\beta=1.650$
	$\gamma=1.729$	$\gamma=1.639$		$\gamma=1.731$	$\gamma=1.653$
Op. char.	(−)	(−)	(+)	(−)	(−)
2V.	50°	80°		65°	70°
Dispersion		$r>v$ str.			$r>v$
Orientation		orthorhombic			
		Z=b, X=a			
Cleavage		(100) good			
		(010) fair			
Pleochroism	X=clear		O=pale blue		
	Y=lt. blue		E=deep purple to pink		
	Z=pale pink				

Acknowledgments

A grant from the Holden Fund of Harvard University enabled the author to visit the Arizona locality. To each of the members of the staff of the Department of Mineralogy at Harvard University utmost thanks are due for valuable aid so freely given in the preparation of this paper.

NOTES AND NEWS

PALEOZOIC PEGMATITES IN THE PENNSYLVANIA HIGHLANDS

Donald M. Fraser, *Lehigh University, Bethlehem, Pennsylvania*

Abstract

Quartz-feldspar dikes have been found in the Hardyston sandstone of Cambrian age where it directly overlies the pre-Cambrian rocks in the Pennsylvania Highlands. The occurrence is in the east end of Morgan Hill along the Delaware River, in the eastern part of Northampton County where the roughly parallel ridges of the Highland area strike nearly east and west.

The quartz-feldspar introduced material occurs in the lower few feet of the sandstone in groups of small lenticular dikes only a few feet long and usually not more than a few inches thick. Microcline and apatite were formed first and were later invaded by an abundance of quartz which has replaced the feldspar to a large extent.

The pegmatitic invasion of Lower Paleozoic rocks has long been recognized in the Philadelphia area but the writer is not aware that it has previously been reported in the Pennsylvania Highlands.

With the finding of definite pegmatitic material of Paleozoic age, it may be reasonably assumed that much of the silicification of Paleozoic rocks of the area has been accomplished by magmatic solutions; also it is likely that at least some of the quartz veins in these rocks were formed from solutions of magmatic origin, which in their less aqueous and more siliceous phases formed pegmatites.

Field Relations

Pegmatitic material in the form of microcline-quartz-apatite dikes are found in the basal part of the Paleozoic rocks of the Highlands where they are cut by the Delaware River in Easton Quadrangle (Fig. 1). The dominant ridge west of the Delaware is known as Morgan Hill, and extends away from the river in a direction a little south of west. The main mass of the hill is pre-Cambrian crystalline gneisses and schists. The Hardyston formation flanks the ridge along its northern side and is cut off at the eastern end by a fault which parallels the southern side of the ridge. The Hardyston which varies from a quartzite to a less densely indurated sericitic arkose, for the most part, dips away from the ridge to the north and northeast. The dikes occur in this arkosic sandstone immediately above the contact with the crystalline rocks which have previously been stated to be pre-Cambrian. Inasmuch as some of the underlying crystalline material is pegmatite there is a possibility that some of it likewise may be Paleozoic in age. The nature of the contact with the Hardyston however lacks the characteristics of intrusion and more nearly resembles a contact of deposition along which recrystallization has occurred. The amount of intruded material of Paleozoic age found in the Hardyston is small, and in all probability, it is not abundant in the underlying crystallines close to their contact with the Paleozoic sediments.

Pegmatites are very common in the pre-Cambrian rocks of the region. They range from those types approaching coarse textured granites to very coarse, truly pegmatitic masses of feldspar, quartz and mica and (or) tourmaline. Other types vary considerably in their texture and composition, some containing andesine and hornblende as neocrystallization products of materials assimilated from basic gneisses, some locally being hornblende pegmatites, and others contain only quartz and tourmaline. Dikes having clean-cut borders are uncommon and the gradation, through several inches or several feet, from pegmatitic material to country rock is the rule.

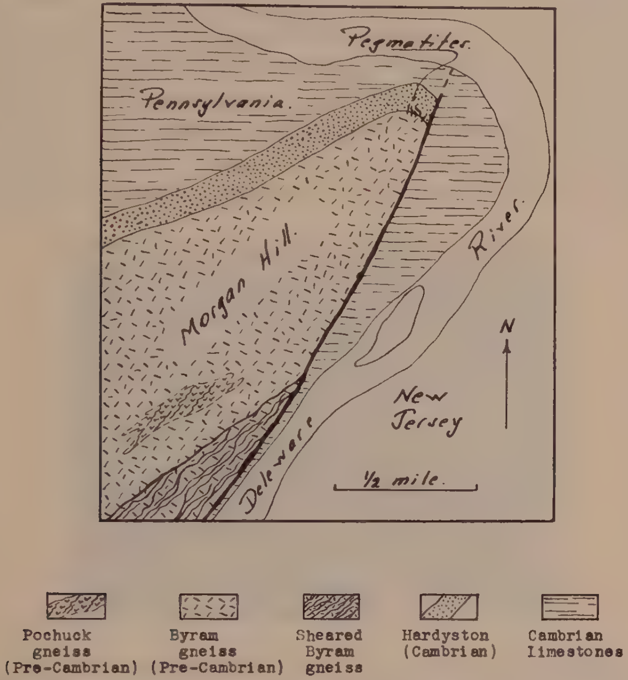


FIG. 1. East end of Morgan Hill showing the areal geology and the location of the pegmatite dikes. Limestone by B. L. Miller. Hardyston by P. B. Myers.

It is apparent that pegmatites of Paleozoic age would be distinguished with difficulty in the areas of pre-Cambrian rocks and only where one is fortunate enough to find them actually cutting Paleozoic sediments may their later age be recognized.

The pegmatitic material observed in the Hardyston varies from subhorizontal irregular lenses, changing in a horizontal distance of less than ten feet from a maximum of five or six inches to less than an inch in thickness, to small dikes extending vertically and sending off small spur-like apophyses that have filled what were apparently gash joints.

The proportional amounts of feldspar and quartz vary considerably. In hand specimens feldspar appears in some places relatively free from other minerals, and in others it is intimately mixed with quartz which may, and often does, make up a large percentage of the dike.

The dikes occur in only the first few feet of the Hardyston above its contact with the pre-Cambrian. The Hardyston itself is only a few feet thick in the outcrop where the dikes appear. There is, therefore, no evidence of a very extensive invasion of pegmatitic material into Paleozoic formations altho further discoveries may extend the upper limit considerably.

Pegmatite dikes[1] and evidence of pegmatitic emanations into Paleozoic rocks of the Philadelphia region are not uncommon, but the evidence of a similar activity in the Pennsylvania Highlands is not so abundant and to the writer's knowledge has not been previously reported. Igneous rocks of Paleozoic age in areas near the Highlands are found north of Beemerville,[2] New Jersey, and near Jonestown,[3] Pennsylvania. The former is a nepheline syenite illustrated in the Folio as an elliptical area lying between the areas of Martinsburg shale and Shawangunk con-

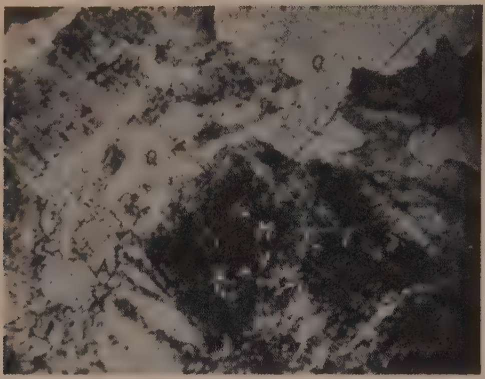


Fig. 2. Microcline (M), apatite (A) and quartz (Q). Note the replacement of the feldspar by quartz. The feldspar is partially kaolinized. Mag. 45 diameters.

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[1] Bascom, F., and others., *U. S. Geol. Survey, Folio* **162,** Philadelphia, Pa.

[2] Spencer, A. C., and others, *U. S. Geol. Survey, Folio* **161,** Franklin Furnace, N. J. Wolff, J. E., described the nepheline syenite.

[3] Gordon, S. E., *Proc. Acad. Nat. Sci., Philadelphia,* vol. **72,** pp. 354–357, 1921. Stose, G. W., Jonas, A. I., *Bull. Geol. Soc. Am.*, vol. **38,** pp. 505–536, 1927.

glomerate. The latter is an occurrence of basaltic material as lava flows interbedded with rocks of Ordovician age.

PETROGRAPHY

In thin section, microcline is found lining the dike walls and extending into the dike proper in irregular masses. It contains occasional grains, or aggregates of grains, of apatite and is extensively replaced in places by quartz (Fig. 2). The quartz may occupy the entire dike except for small amounts of ragged microcline remaining along the walls. In other places it has encroached upon microcline and has penetrated this mineral as arms and irregular areas (Fig. 3). The edges of some microcline grains contain abundant small circular areas of quartz and have numerous concave encroachments of quartz.

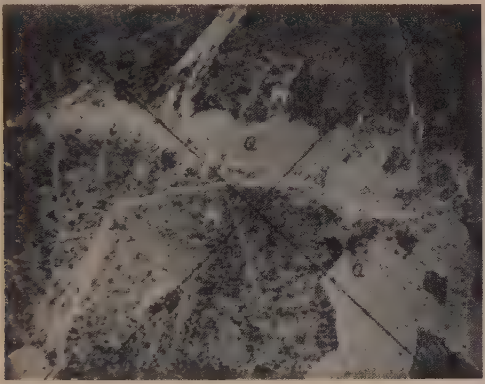

FIG. 3. Quartz (Q) veinlet replacing microcline (M). Note the smaller areas of quartz at the upper center and lower left and the small remnants of feldspar along the margins of the veinlet. Mag. 45 diameters.

Along the walls of the dike, which are much more distinct than the contacts of pre-Cambrian dikes with their wall rocks, grains of feldspar in the sandstone show extended growth, as do also occasional grains of tourmaline.

It is concluded from these features that at first microcline and apatite entered and filled the fractures. At this time some feldspar grains, and probably the tourmaline also, suffered extended growth in the wall rock. Quartz then entered, permeated the vein material and extensively replaced the microcline.

It is likely that the dikes where now found indicate the upper limit reached by the pegmatitic juices beyond which the filling more and more closely approached vein formation. Their igneous affiliations, however, are fairly definite and hence the presence of a granite magma in the proximity of the Highland area, in Paleozoic time, is indicated.

If we now consider the abundance of quartz veins found in the region and the extensive silicification of the Hardyston and the pre-Cambrian rocks, it is apparent that the entire Highlands, and the limestone and shale areas adjacent, have been subjected to an extensive permeation by silica bearing solutions. Much of this material which has previously been tentatively assumed to be of meteoric origin, may well be of magmatic origin as is indicated by the finding of pegmatitic material in the district.

In addition, it should be pointed out that there is now a source for magmatic solutions which may have formed the zinc deposits at Friedensville, as well as other zinc and lead deposits of eastern Pennsylvania, which have been thought to lie outside the areas invaded by such solutions.

THE PREPARATION OF ORIENTED POLISHED SECTIONS OF SMALL SINGLE CRYSTALS

M. J. BUERGER AND J. S. LUKESH, *Massachusetts Institute of Technology, Cambridge, Massachusetts.*

Polished sections are ordinarily made of mineral aggregates. The orientation of a crystal under observation cannot be easily or accurately determined in such sections. In many instances information of great value could be obtained if polished sections of known orientation could be prepared. In a recent investigation[1] it was found necessary to prepare polished sections of tiny arsenopyrite crystals (from one to a few millimeters in diameter) in such a way that the plane of the section might have any predetermined orientation. For this purpose a simple instrument and technique were developed which gave excellent results. Undoubtedly many crystallographic problems may be solved by the use of oriented polished sections, so the technique of preparing them is herewith described.

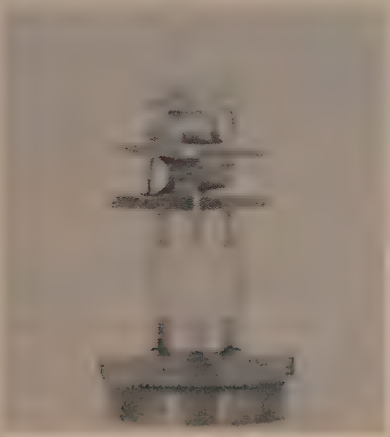

FIG. 1. Adjusting crystal holder. $\times\frac{2}{3}$.

The crystal is cemented to a holder (Fig. 1), which may be fitted to a goniometer for the purpose of orienting the crystal. After appropriate adjustment the holder is removed to a small grinding and polishing device (Fig. 2) where the actual section is prepared.

The crystal is mounted on the adjusting head with the aid of a cement known as *Coecal*, made by the Coe Laboratories of Chicago. Enough of the crystal should be permitted to project above the cement to allow appropriate orienting surfaces to give reflections when the head is in position on the goniometer.

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[1] Buerger, M. J., The symmetry and crystal structure of the minerals of the arsenopyrite group: *Zeit. Krist.* (A), in press.

The crystal adjusting holder is similar to the customary goniometer adjusting crystal holders except that, for the sake of ruggedness, convenience is sacrificed for simplicity. There are no translation sledges, and the two orthogonal rocker arcs are replaced by hinges. These are freed for adjustment by loosening the screws, and locked by tightening them. The entire adjustment head fits on a standard fitting on the goniometer spindle which accomodates removable adjusting devices of all sorts (for example, adjusting heads for x-ray apparatus[2]). The crystal adjusting head fits by the same means to the feed arm of the grinding device. To promote rigidity in this position, the length of the head is reduced by the removal of a central pillar.

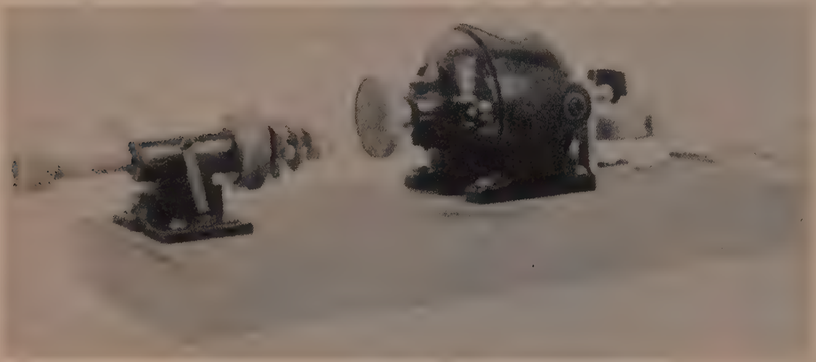

Fig. 2. Apparatus for grinding and polishing oriented sections of small crystals. ×⅓.

The grinding is done by holding the crystal against a rotating lap. The motive power is furnished by a small 1/150 H.P. Westinghouse motor operated directly from the standard power supply, but with the speed reduced and appropriately adjusted by means of a rheostat. During the grinding and polishing operation the crystal is held against the lap by means of the feed knob seen at the extreme left of Fig. 2. This places the crystal in an eccentric position on the lap, the degree of eccentricity being varied during the operation by depressing the lever (seen above the left center of the feeding device) against a spring.

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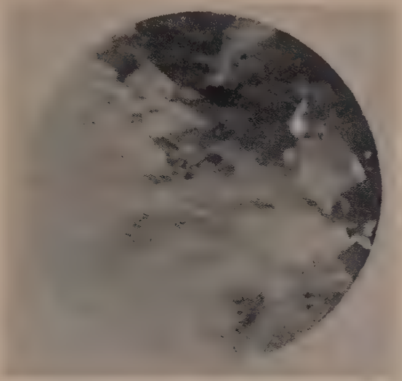
[2] Buerger, M. J., An apparatus for conveniently taking equi-inclination Weissenberg photographs: *Zeit. Krist.* (A) vol. **94**, pp. 91–92, 1936.

We have obtained good results by the following procedure: For small crystals a few millimeters long, the grinding is done entirely with #000 emery paper as the abrasive. For larger crystals #1 is used first, followed by #000. These abrasive papers are held to the disk by means of a tight fitting ring. The rotation speed should be fairly high for large crystals but low for small ones.

After the correct surface is exposed by grinding, the abrasive paper is removed and a fine or medium grade of linen substituted for subsequent polishing. The polishing abrasive is chrome oxide, which is rubbed on the linen dry. The rotation speed for polishing should be relatively high. In order to eliminate polishing streaks on the surface, the crystal is moved back and forth across the lap by operating the eccentricity lever of the feed.



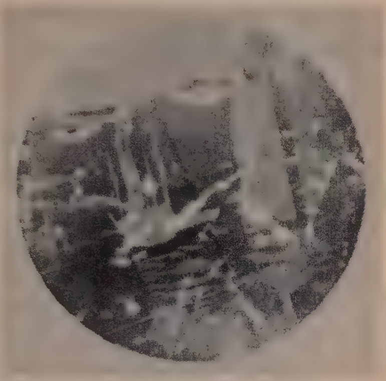


FIG. 3. Polished surface of small Joplin marcasite crystal, showing lineage structure. Surface approximately parallel with (010) (new orientation). Crossed nicols. ×55.

FIG. 4. Polished surface of small Sulitjelma danaite crystal showing polysynthetic twinning. Surface approximately parallel with (010) (new orientation). Crossed nicols. ×55.

Figs. 3 and 4 show examples of the polished sections obtained by the procedure outlined and photographed between crossed nicols to bring out the structures under investigation.

We are greatly indebted to Mr. O. von der Heyde for constructing the apparatus from rough sketches and for improving our original design.

AN IMPROVED VANDERWILT ROCK SAW

G. D. Emigh, *University of Arizona, Tucson, Arizona.*

A simple and inexpensive device for sawing rock specimens up to 7 inches square in cross section was designed and described by Vanderwilt.[1] Some changes in Vanderwilt's original design were made by the present writer, and a machine was constructed at the University of Arizona which incorporated these changes. It has been in operation for more than a year and has given very satisfactory results.

Vanderwilt's article describes the original saw clearly and concisely, but for the sake of completeness the main features of the machine will be briefly described. The saw consists of a straight blade of sheet iron which is drawn back and forth across the rock specimen by means of an arm connected to an eccentric on a pulley. Power is provided by an electric motor connected with belts to a series of pulleys. Abrasive is automatically fed with water under the saw edge, and the dragging of this abrasive under the moving blade provides the cutting action.

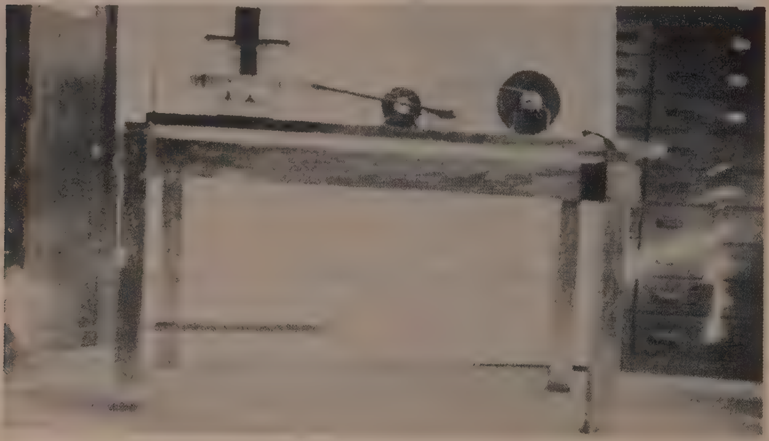


FIG. 1. Vanderwilt Rock Saw and Table.

The photographs accompanying this article show the mechanical construction of the saw. It is a compact unit contained on a plank 12″ wide and 6 feet long. A one-fourth h.p. electric motor running at a speed of 1500 r.p.m. is connected by $\frac{1}{4}$″ round leather belting to three pulleys. These reduce the speed so that the last pulley—to which the connecting rod moving the saw blade is fastened—runs at the desired speed. There are four pulleys in the speed-reducing unit. The one on the motor is made of aluminum and can be purchased at any hardware store. The largest pulley is made of wood, and the other two were machined out of steel. Bearings are made of brass, and the bearing supports are strap iron bent in the shape shown in the diagrams, and bolted to the plank base.

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[1] Vanderwilt, John W., A rock saw: *Am. Mineral.*, vol. **19**, pp. 224–229, 1934.

The connecting rod joining the eccentric and the saw blade is made of ½ inch lead pipe. Where it connects to the eccentric, a T-joint 1½ inches wide was put on to act as the bearing. This gives a long enough bearing surface so that the connecting rod moves in a vertical plane without sidewise motion. The length of a stroke is 4 inches. The saw is made of 16-gauge sheet iron 18 inches long and 2 inches wide. It fits into a slot in the end of the connecting rod and is fastened there with a small bolt. The blade works between four iron guide posts which keep it in a fixed vertical plane.

The rock specimen to be cut is clamped in position under the blade with a wooden clamp. Details of this clamp can be seen in the diagrams. It consists of a short piece of board with a hole bored in it, in which fits a long screw coming from the plank base. The front end of the board fits on top of the specimen and the back end is blocked up with wooden blocks. Tightening on the screw then clamps the board down firmly on top of the specimen. The specimen rests on a wood block 2 inches thick which in turn is placed in a pan. The block should project above the pan. The reason for this is that the saw blade seldom works perfectly flat—especially after it becomes worn—and to avoid cutting the sides of the pan, the pan must be lower than the block. The pan catches the cuttings and worn abrasive washed from under the saw blade. It is provided with a spout to allow overflow of the water.

The feed box which holds the abrasive is a separate unit, and is clamped on top of the wooden clamp holding the specimen. The feed box is a wooden box with celluloid sides in which two small holes are bored opposite each other. A string passes through these holes, and is fastened on one end to a rubber band which in turn is fastened to an iron post. The other end of the string is fastened directly to the connecting rod. Each time the connecting rod moves back it pulls the string forward, and on the forward stroke the rubber band pulls the string back again. As the string moves back and forth through the holes it pulls out the abrasive which falls on a tin chute, then into a rubber tube which directs it onto the specimen. A second set of tubes near the abrasive tubes are for water which is allowed to drip slowly. The water supply is in a large glass jar set far enough above the saw so as to feed by gravity. The water serves three purposes; it washes the abrasive under the saw, it lubricates the blade, and it washes the cuttings from under the blade. The abrasive and water fall onto a sloping shelf of plaster of Paris which is made on the specimen itself. The slope is made about 1½ inches wide and extends across the entire length of the specimen (see Fig. 2). The slope, of course, is toward the saw blade, and the abrasive falling on the slope is washed down and into the saw-cut by the water.

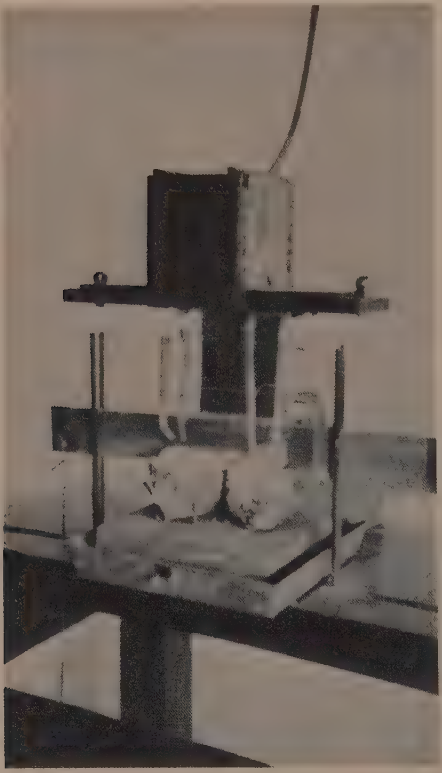

Fig. 2. Abrasive Feed Device.

In order to increase the speed of the cutting action, and to help steady the blade, weights are suspended under the saw by means of a wire suspended from each end of the blade. These wires pass through slots cut in the plank base, and under the table are fastened to a stick of wood. Weights are then suspended from this crosspiece, and by moving the weights along the bar, a position can be found in which the blade rides evenly on the specimen.

This completes a generalized summary of the saw. It might be well now to go more into detail concerning its successful operation.

The feed box which is shown in detail in the figures differs from that described by Vanderwilt only in the way the abrasive and water are fed to the specimen. A fairly stiff piece of wire is fastened to each rubber tube and to the frame of the feed box. By bending this wire the tubes can be directed so as to feed to any position on the plaster of Paris slope. With small specimens the tubes may be too short to reach within an inch or two of the specimen, and glass extension tubes are placed in the ends of the rubber tubes. These glass tubes and the wires holding them in position can be seen in Fig. 2. The flow of water coming from the water tubes is controlled by clamps. It is important not to let the water touch the abrasive tubes, for as soon as the latter get wet, the carborundum packs and clogs the tube. The amount of abrasive pulled out of the holes by the moving string varies with the distance the string is pulled back and forth. With a hole slightly larger than a common string, a $\frac{1}{4}$ to $\frac{1}{2}$ inch stroke is sufficient. One end of the string is fastened to the connecting rod, which, having a 4″ stroke would pull the string four inches. This difficulty is overcome by fastening rubber bands to each end of the string, and by varying the number of rubber bands a differential pull can be made which will produce any length stroke desired. Experiments were run using different sizes of abrasive from 60-mesh to 200-mesh and finer. Sixty-mesh abrasive is not only too coarse to cut fast but also gouges the sides of the cut badly. Eighty-mesh cuts faster than any other size, and is the size used, although 100-mesh is nearly as satisfactory. With an abrasive finer than 100-mesh, the cutting action is slower but a much smoother cut is made. In cutting a very choice or friable specimen one should use 150-mesh material as this causes practically no gouging on the walls. The abrasive can be used repeatedly, but after each cut it is reduced in size. Eighty-mesh carborundum after two cuts through quartz is reduced largely to 100-mesh.

It is extremely important to clamp the specimen firmly in position, otherwise, under the vibration and saw movement it will work loose, bind the blade and stop the saw. Many specimens are so shaped that they can be clamped easily in a firm position, but we have found it advisable to brace the bottom of specimens with nails driven into the wooden supporting block and by means of wooden wedges. By taking a little time one can clamp any shaped specimen into a cutting position. The machine here described can cut a specimen up to 8″×10″ in cross-section. The saw blade works much more evenly on a long cutting surface. No difficulty is encountered in cutting a small rock, but the blade will run more evenly if two or more small specimens are cut at a single operation.

The saw blade hangs loose from the end of the connecting rod. With a speed of 120 strokes a minute one can adjust the weights so that the saw rides evenly, but when the number of strokes is increased to 190, the saw often "flops" badly in spite of adjustments of the weights. This trouble can be largely overcome by putting a metal wedge in the open slot space in the connecting rod just behind the blade. In this way the connecting rod and the blade become one stiff unit.[2] The 20-inch connecting rod is long enough so that the vertical motion at its end is less than an inch and the extra length of the saw cuts this down still further. The blade wears down slowly, and when it has worn down about $\frac{1}{2}$-inch it can be turned over and the reverse edge used. At first, the saw was run at a speed of 120 strokes a minute. Later this was increased to 190 by replacing the 2 inch motor pulley with one $2\frac{1}{2}$ inches in diameter. The higher speed increases the cutting action considerably, but at the same time causes trouble at the start before the saw has had time to "seat" itself. Our practice is to start the operation at 120 strokes a minute using the smaller pulley, then, after the blade is running smoothly in its cut, change to 190 strokes a minute by replacing the small pulley with the larger one. The leather belt is kept loose enough to fit both pulleys. Aside from this, it is better to have the belt loose so that when the saw sticks, as it will do occasionally, the motor pulley will slip, preventing the motor from burning out.

The heavier the weights that are suspended under the blade, the faster is the cutting action, providing the speed is not greatly reduced. We use weights of from 5 to 15 pounds.

Following are the cutting rates of the saw using 100-mesh carborundum, 7 pound weights and 190 strokes a minute:

quartz —$\frac{3}{4}$ to 1 inch an hour
calcite —4 inches an hour
quartz-sulfide ore—2 inches an hour

The width of a specimen does not seem to affect the cutting speed very appreciably. A specimen 7 inches wide will cut apparently as fast as one 3 inches wide.

To anyone contemplating the construction of one of these saws it would seem advisable to use at least a $\frac{1}{3}$ h.p. motor in order to use heavier weights under the blade. The ideal motor would be one with adjustable speeds, but such a motor is more expensive than the constant speed motor. Our arrangement—interchanging motor pulleys—is quite satisfactory. If a constant speed machine is used it should not be run over 120 strokes a minute. The feed box could be improved by making it V-shaped rather than square, thus doing away with dead space. One might improve the blades by cutting a few V-shaped notches along their edges which would help to work the abrasive under the moving edge.

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[2] Vanderwilt recently has developed a device which tends to eliminate completely "flopping" of the saw blade. He uses a longer weight bar than the one shown in Fig. 1, and fastens one end of the bar with a pivot to the table leg. With this system the saw blade is kept in approximately a horizontal position by shortening at intervals the wires coming from the saw blade. A small link chain has been found convenient here, for by dropping a link every hour or two the saw blade can be kept nearly horizontal. Vanderwilt reports that since using this device he has had no trouble with the blade sticking.

Following is the approximate cost of the machine described here:

Motor	$7.00
Table	8.00
Labor	10.00
Miscellaneous parts	3.50
10 saw blades	1.50
	$30.00

The writer wishes to acknowledge his indebtedness to Dr. M. N. Short for encouragement and criticism and to Mr. E. M. Patterson for assistance in working out the details of the mechanism.

BOOK REVIEWS

MINERALOGY. Third Edition, KRAUS, E. H., HUNT, W. F., AND RAMSDELL, L. S., McGraw-Hill Book Co., New York, **1936.** ix+638 pp., 812 figs. Price 5.00.

The new edition of this splendid text leaves little to be desired as an authoritative introduction to the science of mineralogy. The many years of successful teaching experience of this competent staff of authors is clearly reflected in the general excellence of this book. Those who are familiar with the earlier editions will be favorably impressed by the notable changes made in the discussions dealing with polarized light, and crystal structure and *x*-ray analysis, in recognition of the rapid advances made in these phases of mineralogy during the past few years. Proper emphasis has also been placed on the occurrence and commercial uses of the common and important minerals which are discussed in two comprehensive and exceptionally well written chapters comprising a large portion of the text, thus acquainting the beginner with the importance of mineralogy in scientific and industrial development, and in national well-being.

The chapters dealing with crystallography include only the important crystal classes. The discussion is adequate, clearly written and essentially the same as that of the earlier editions. Some may question the value of photographs of crystal models which have been used abundantly throughout these chapters. They are, however, employed as a supplementary aid in the interpretation of the clinographic projections of the various crystal forms, and the reviewer has found such photographs a practical aid to the student in his laboratory studies.

An excellent chapter on qualitative blowpipe methods for the identification of the commoner elements precedes that portion of the book devoted to descriptive mineralogy, but unfortunately, the large size of the text prohibits the inclusion of a complete set of tables arranged for identification of minerals by blowpipe methods. One of the many desirable features of this book is the set of descriptive tables arranged for the sight determination of minerals bound in the back of the text. For some years these tables were published as a separate volume to serve as a guide to the beginner in his laboratory identification of the common minerals. The binding of these tables with the text material affords a convenient reference for both student and teacher. The efforts of the authors in the careful preparation of these determinative tables have made possible a rather unique, though simple, usable means of mineral identification based on the more readily determinable properties, and many years of experience with elementary classes have convinced the writer of their value as a laboratory guide.

The book carries a large number of good illustrations, carefully chosen, including cuts with brief biographical sketches of eminent scientists whose classic contributions to the field of mineralogy are well known. The selection of subject matter, the simple style, and the accuracy and directness of statement are most commendable, and serve to make this text both readable and authoritative.

A. P. HONESS

SNOW STRUCTURE AND SKI FIELDS. By G. SELIGMAN, B. A., F. R. MET. SOC., with an Appendix on Alpine Weather by C. K. M. Douglas, B.A., F. R. Met. Soc., with nearly 400 illustrations, Macmillan, **1936**, pp. 555.

This luxurious volume, the price of which is set at $9.00, is not alone a volume for the alpinist and the ski expert, but is a solid scientific work of a kind that has seldom before appeared. It is in fact in large part a technical treatise on the snow, its physical properties, and the changes it habitually undergoes during the processes of precipitation, melting, under pressure of dry or moist air, etc., etc.

The scientific study of snow has hitherto been undertaken by but few experts, both because of the inclement and inaccessible places where this can alone be done with any thoroughness, and also because laboratory technique has not been much developed for these special conditions. Up to the present, most of the more valuable studies have been made within the polar regions, in high mountains, or by engineers who have had to concern themselves with the practical problems connected with transportation and avalanching.

Seligman has made a great advance by instituting extended outdoor laboratory studies with the use of fairly simple apparatus, which has however permitted microscopic studies of the snow structures for most types. Out of this study has grown a great collection of photographs and almost 400 of these, and other illustrations, are reproduced in this book of 555 pages. So large a proportion of them are half tones that it has been necessary to employ a highly surfaced paper.

The book is the first systematic treatment of the subject of snow and so the author has found it necessary to give many new names for types which either have not before been described or else had not been clearly shown in their relation to others.

The book is divided into three parts. Part I, which comprises more than one-half of the book, if the appendices are excepted, after developing the method of study is devoted to the nature and structures of snow and the processes by which changes are brought about—air hoar and rime firnification, wind packing, drifting and erosion, cornices, stratification and water movements in snow.

Parts II and III are given over to avalanches, especially conditions which favor their formation, their slow movement; dry, wet, wind-slab, and ice avalanches, mixed avalanches and avalanches in series. There is then taken up from the point of view of the skier and alpinist the matter of safeguarding against accidents from avalanches, based upon the indications of danger which have been supplied by scientific studies and by experience.

It is not too much to say that this book has made a large contribution of original scientific research on the subject of snow, and has done a service of high order in bringing into an essentially new branch of science a thorough organization. The work is thoroughly documented and the literature supplied, which hitherto had been scattered, is very impressive. A detailed index of no less than 13 pages fittingly caps the effort. The work is surprisingly free from typographical errors in view especially of the foreign languages so largely represented in the references. Its timely appearance is very nearly synchronous with the organization of an International Commission on Snow which, under the chairmanship of Professor J. E. Church of the University of Nevada, held its first conference in Edinburgh in September.

William H. Hobbs

NEW MINERAL NAMES

Additional Data

Herzenbergite (Kolbeckine)

Paul Ramdohr: Vorkommen und Eigenschaften des Herzenbergits: *Zeit. Krist.*, vol. **92**, pp. 186–189, 1935.

Chemical Properties: From mineralographic and *x*-ray studies, identical with SnS, hence not Sn_2S_3.

Mineralographic Properties: Reflection-pleochroism weak in both air and oil, ∥ to (001) paler and more blue white, ⊥ to (001) dark and in contrast, somewhat yellowish white. Extinction parallel; in 45° position with crossed nicols, red to yellowish red tone, passing on slight rotation to grayish blue to greenish blue. Inner reflection, rarely observable in oil, deep reddish brown.

Etch Reactions: HCl positive; KOH etching and brown precipitate; negative with HNO_3, $FeCl_3$, $HgCl_2$, and H_2O_2.

Occurrence: With pyrite, cassiterite, stannite, "brown stannite," blende and chalcopyrite, as hydrothermal sulfide. Also found very sparingly at the Stiepelmann mine, Arandis, SW. Africa.

W. F. Foshag

Taosite

Jacques de Lapparent: Les étapes du métamorphisme des émeris de Samos: *Compt. Rend. Acad. Sci.*, Paris, vol. **201**, No. 2, pp. 154–157, 1935.

A mineral believed to differ from corundum, showing the following properties: Uniaxial negative; very distinctly pleochroic, ϵ=clear yellow; ω=reddish yellow brown. N about 1.78; birefringence 0.035. It occurs as thin plates included in spinel, and arranged parallel to the direction of the faces of the octahedron. From the emery of Samos, Greece.

W. F. F.

Clinoferrosilite

N. L. Bowen: Ferrosilite as a natural mineral: *Am. Jour. Sci.*, [5], vol. **30**, pp. 481–494, 1935.

Chemical Properties: Iron metasilicate; $FeSiO_3$. Deduced from the optical properties of the mineral.

Crystallographic Properties: Prism angle 90°50′.

Optical Properties: Transparent, with trace of amber in minute crystals. $\alpha=1.763\pm.002$, $\gamma=1.794\pm.002$. $c: \gamma=34.5°$ β nearly equal to α; 2V very small; plane optic axes is probably parallel to $\{100.\}$

Occurrence: Found as minute needles in lithophysae in obsidian, with anorthoclase, cristobalite, magnetite, fayalite and biotite, near Lake Naivasha, Kenya Colony, Africa. Also from Coso Mountains, California; Hrafntinn-uhryggur, Iceland; and Obsidian Cliffs, Yellowstone National Park.

Relationships: A member of the pyroxene group.

W. F. F.